MONTANA
DEPARTMENT OF HIGHWAYS

HYDRAULICS MANUAL

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16. Abstract

The objective of this project is to present a comprehensive Hydraulics Design and Procedure Manual. The purpose of this Manual will be to furnish information to field and office personnel which will bring about uniformity in hydraulic designs and which will be in conformity with accepted policies at the Montana Department of Highways and the Federal Highway Administration. Included in the Manual is a description of survey information required for hydraulic design, the methodology for performing various hydrologic analyses, and the procedures for performing most highway related hydraulic design.

17. Key Words	18. Distribution Statement
Hydraulics, Hydrology, Culverts, Bridges, Rest Areas, Erosion, Irrigation, Hydraulic Surveys, Storm Sewer	Montana Department of Highways, Federal Highway Administration, and cooperating agencies. Additional copies available from Montana Department of Highways

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ACKNOWLEDGEMENTS

The purpose of this Manual is to bring together in one publication all information that is normally used by the Department of Highways for hydraulic design. Much of the material used in the preparation of this Manual was by no means original and was obtained from other manuals and publications. Many portions ranging from single paragraphs to major sections were lifted verbatim, as nothing would be gained by rewording.

Particular credit should be given to the Federal Highway Administration under whose funding this Manual was developed and whose Hydraulic Engineering Circulars provided a great deal of material used in the Manual.

The faculty and staff of the Civil Engineering Department of Montana State University who developed much of the hydrolical data for use in the Manual are also gratefully acknowledged. Thanks are due to the National Weather Service, the Geological Survey, the Soil Conservation Service and the many other agencies and organizations who collected and supplied data necessary for the development of a Manual of this type.

A very special thanks is due to Mr. Eugene H. Larson, former Manager of the Hydraulics Unit of the Montana Department of Highways who foresaw the need for this Manual and under whose leadership the Manual was written.

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POLICY AND PROCEDURES

MONTANA DEPARTMENT OF HIGHWAYS
Helena, Montana 59620

MEMORANDUM

TO: Holders of Montana Department of Highways Hydraulic Manual

FROM: Stephen C. Kologi, P.E., Chief, Preconstruction Bureau

RE: Hydraulics Manual Update

DATE: November 4, 1981

Under a cooperative agreement, the U.S. Geological Survey has completed a report providing revised techniques for estimating magnitude and frequency of floods in Montana. We are hereby providing you with a copy of this report (Open-File Report 81-917) which is to be incorporated into the Hydraulics Manual provided you about six years ago.

We are unable to completely update the Hydraulics Manual at this time or provide copies of all the materials referenced below; however, this material is to be incorporated into the manual as follows:

a. Note in Section 3.3 that Log-Pearson Type III is used following the procedures outlined in the United States Water Resources Council's Bulletin #17A, "Guidelines for Determining Flood Flow Frequency." By this reference Bulletin #17A shall be incorporated into the Hydraulic Manual.

b. Note in Section 3.4 that references to the Dodge Method are to be replaced with the methods of Open-File Report 81-917.

c. Users of the Hydraulic Manual shall become familiar with the limitations of the regression equations presented in the Open-File Report and as discussed on page 16 of the report.

d. As in the past, the Hydraulics Manual does not attempt to show which flood prediction method is most appropriate for any given area or stream site but merely presents the methods commonly used. Users must exercise sound hydrologic judgment when evaluating each individual site.

e. We hope to be able to provide an update to the manual in the near future which will provide guidance on the requirements of FHPM 6-7-3-2. Until that time, FHPM 6-7-3-2 is hereby incorporated into the manual by reference.

f. After making the above notations, this memo shall be filed under Section 1 (Policy and Procedures).

In the past we have received numerous requests for copies of our Hydraulics Manual and previous Open-File Reports and we anticipate similar request for this report. If you feel that this Open-File Report will not be used by you or your staff, we request that you return it to the Hydraulics Unit.

Thank you for your cooperation.

34:SCK:CSP:cg:6C

Stephen C. Kologi

Attachment

DISTRIBUTION w/Attachment

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SECTION 2
SURVEYS

Introduction

No matter how precise the hydrology of a watershed may be established and exacting the hydraulic computations, the end result will be no better than the survey. This does not mean the survey should be exacting to the nearest hundredth of an inch - although reasonable accuracy is necessary - but that the survey portrays the true situation. It is to this latter item - the true situation - that this Chapter is directed.

The object of this Chapter is to give the survey personnel guidelines as to what information is needed and why it is needed. All hydraulic surveys are different and many times items will be encountered that are not discussed in this manual. The survey personnel should always feel free to phone the Hydraulics Unit and discuss with them what information should be submitted for a particular hydraulic site.

The old saying, "A picture is worth a thousand words" is doubly true when discussing a hydraulics survey. The need for adequate photographs cannot be over emphasized. A great deal of information can be submitted in photographs. Photographs should always be well labeled on the back.

The survey personnel should always make any comments or recommendations that they feel might be pertinent to the hydraulic design. A short discussion of the hydraulic history of a site is often helpful in the hydraulic design.

SECTION 2.1
WATERWAYS

2.1 SURVEY DATA FOR DESIGN OF WATERWAYS

2.11 GENERAL

To insure that all of the watershed data is submitted, Form HYD-1 is provided to record the basic data for the watershed. Other pertinent data should be submitted with Form HYD-1 on separate sheets. This form shall be completed by the survey personnel for all stream crossings with drainage areas of one square mile or more. Form HYD-1 should be filled out with ink or filmograph (plastic) leads to provide a more permanent record of the survey data.

The following paragraphs list and describe the watershed data required by Form HYD-1. The data for each item required on the form shall be placed on the appropriate blank completely and accurately. Additional sheets should be used when sufficient space is not available on the form. All supporting documents, such as survey notes, photographs, etc. shall be submitted with Form HYD-1. All photographs should be labeled, dated, and referenced on the back of the photograph. Photographs showing the frozen stream and/or snow covered ground usually do not show desired detail and should be included only if no other photographs are available.

Some of the information requested will not be readily available and will require some research or consultation with appropriate people to obtain.

2.12 WATERSHED DATA

This section contains means for the survey personnel to describe watersheds in terms that will be usable by the designer. Other items such as debris and ice are included since they have a direct bearing on the type of structure to be selected.

Area

The total drainage area of the watershed should be estimated to determine whether Form HYD-1 should be completed. If the total drainage area is near one square mile, or, if the drainage area cannot be determined, the form should be filled out completely.

There are several methods for estimating the drainage area. The easiest is the visual estimate. This method should be used only for small drainage areas which can be totally viewed.

Maps and aerial photos are by far the quickest method for determing drainage areas. County maps provide a doubtful degree of accuracy except on the larger drainage areas. The county maps do have an advantage in that they provide state wide coverage. The Army Map Services series of contour maps with a scale of 1:250,000 and contour interval of 200 feet, can be used for drainage areas down to several square miles. These maps also provide statewide coverage. The U.S.G.S. "quad sheets" with scales of 1:250,000 (150 feet contour interval), 1:62,500 (40 feet contour interval), and 1:24,000 (20 feet contour interval) provide a much more accurate area determination, but coverage is not statewide. When ever aerial photos are available, they will be found to be valuable for estimating drainage areas.

Sometimes there will be parts of the total drainage area that do not contribute to the run off from the basin. These may be low areas, swamps, lakes, etc. These areas should be determined as accurately as possible and the information provided on Form HYD-1 so it may be compensated for. If this area is significant, an explanation should be attached to the form.

Land Use and Cover

Land use and vegetative cover have a great deal of affect on the run off from a drainage area. Therefore, estimates of the percentages of the various types of use and cover should be given. The percent of forest cover is an important parameter in determining run off in many parts of the State. Following is a list of other types of cover that might be given consideration:

- Forest Lands
- Row Crops
- Range Lands
- Grain
- Pasture
- Permanent Meadow
- Farmsteads
- Residential Areas
- Commercial Areas

Any other type of land cover or use that may be significant should be given, also.

On smaller watersheds, the various percentages can be visually estimated. If there is likely to be a change in land use for a portion of the drainage area at some time in the future, some mention should be made of the change.

Debris

Flood flow reaching a culvert or bridge nearly always carries debris which may be either floating material, material heavier than water, or a combination of both. Debris must be considered in the hydraulic design because it can be deposited at the culvert or bridge entrance, thus impairing its operation. A thorough study of the extent and type of the debris orginating in the drainage basin is essential for proper design.

The type of debris has been classified into the following groups:

1. Very light debris or no debris
2. Light debris - small limbs or sticks, orchard pruning, and rubbish
3. Medium debris - limbs or large sticks
4. Heavy debris - logs or trees
5. Other - city trash, old car bodies, etc.

The group that best exemplifies the debris from the drainage basin should be indicated on Form HYD-1. If the "Other" classification is checked, a short discussion of what the debris consists of should be attached. Possible future changes in the type of debris that might result from changes in land use in the drainage basin should also be noted. As an example, logging in a previously virgin area could change the nature of the debris problem from one of "medium debris" to "heavy debris".

An estimate of the quantity as well as the type of debris is needed by the designer so that adequate debris storage can be provided. Information on the types and quantities of debris resulting from past floods can be an invaluable guide in selection of the type of debris control structures. Such information may be secured from maintenance personnel, from inhabitants of the immediate area or by personal observation.

Ice

Ice conditions, like debris, have a direct bearing on the type of

structure and substructure used. Ice can cause damage at hydraulic structures in two ways: (1) ice can exert high forces or pressures causing a structure to buckle or collapse, either by thermal expansion during freezing or by impact of large chunks of ice on the structure at high velocities. (2) ice can plug the waterway causing flooding to upstream property and possible damage to the structure.

The potential for ice damage at a crossing should be determined and indicated on Form HYD-1 as Light, Moderate, or Severe. If it is determined that the ice damage could be severe, a discussion of the type of damage and how it could be caused should be attached. Maintenance personnel and local residents may aid in establishing whether or not there is a potential ice problem.

Unusual Watershed Characteristics

Sometimes a watershed is encountered whose characteristics differ significantly from those expected for watersheds in that vicinity. When an unusual characteristic is encountered it will be the responsibility of the survey personnel to write a detailed description of the unusual feature and attach it to Form HYD-1. Following is a brief discussion of several unusual characteristics that might be encountered and what information should be given about them.

Streams which get a great deal of their flow from springs are difficult to make runoff predictions for. When such streams are encountered, the location of the springs within the reach and an estimate of their flow should be given. Because of the difficulty in predicting runoff for such a stream, descriptions of other crossings both upstream and downstream should be given. The following information should be given in the description: size of pipe or area under bridge, type of entrance, length of pipe, type of pipe, height of fill, and historical adequacy.

Dams can also affect the runoff and complicate runoff predictions. They should be adequately described so their affect can be considered. Large

government dams need not be described because of a record of these dams is readily available. The small stock dams are of primary concern. The description of the dam should include the name of the owner and builder, the type of material (earth or concrete), height, location in drainage basin, approximate area of the reservoir when full, and a detailed description of the spillway and outlet control works.

Water Surface Elevations

The water surface elevations should be measured at the centerlines of the survey. If an existing structure makes it impossible to measure the elevation at centerline, they should be measured at the upstream end or edge of the structure and a note added to Form HYD-1 indicating where they were taken.

The elevation of the water surface on the date of survey should be taken and shown on all of the cross sections in Section 6 of the form. The low water elevation should be the approximate elevation of the water surface at its lowest point during an average year. If the stream goes dry at some time during the average year, it should be so indicated. Local residents might be able to help in establishing a low water elevation.

The high water elevation requested on Form HYD-1 is the historic high water elevation. This elevation can be established in several ways. There may be visual signs such as drift lines or water stains that will indicate the high water mark. Local residents will many times remember how high the water got at certain points and may help establish the high water elevation. Written records, such as newspaper stories, may also help establish the high water elevation. The date and the cause of the high water should be given if they can be determined.

Establishing the location, nature and elevation at which damage would occur from upstream flooding is an extremely important part of this section. Some sites may have several damage elevations. The elevation, and brief description of the damage should be located in Section 8 (or Section 5, if the scale is

, of Form HYD-1.

If the stream being crossed contains game fish which must pass through the structure to spawn or for some other reason, this should be indicated.

2.13 EXISTING STRUCTURES

The purpose of the existing structure information is to aid in establishing the size of the proposed structure. The capacity of the old structure together with the knowledge of how well it has carried past floods will aid in determining the size of the new structure. The existing structure may also influence the hydraulics at the proposed crossing if it is left in place.

The historical adequacy of the existing structure and the high water elevation can be determined by visual marks, by talking to local residents, and in some cases by old newspaper accounts. The high water elevation should be measured at the upstream edge of the structure.

2.14 EROSION AND GEOLOGY DATA

The information requested in the Erosion and Geology Section is self explanatory and will be used to determine what type of bank protection will be used and when to use it. If the scour is very severe, a short description giving depth, etc. should be attached to the form.

The channel stability of both bottom and banks should be indicated. A degrading channel is one in which the bottom is being eroded away and is lowering. An agrading channel is one in which the water is depositing material and is building up.

The chemical properties of the soil and water will be used to determine whether steel or concrete pipe culverts will be used. The lab should be consulted when determining the chemical properties.

2.15 LOCATION SKETCH

The purpose of the location sketch is to show the general topography

of the crossing area. This sketch should show the stream meander and the location of all existing roadways, roadway structures and buildings in the area plus the locations of channel cross sections plotted in Section 6.

2.16 CROSS SECTIONS

The channel cross sections are the most important part of the survey data collected. Care should be taken to see that they accurately describe the channel. A minimum of three cross sections are required for every crossing and some of the more complex crossings will require more. If there is not enough room provided on Form HYD-1 for all of the cross sections, the extra ones should be plotted on an additional sheet of cross section paper and attached to the form. The location of each section taken should be indicated in Section 5 and 8.

Each section should be taken normal to the direction of flow at flood stage. Since the area of flow is determined from the cross sections, an improperly oriented section may produce a large error. Each section should be extended far enough to extend above the maximum possible flood. Sometimes this will require a cross section of a very wide flood plain but this is information that is required and must be taken.

Another very important feature of a cross section is the location and classification of vegetation and streambed material. Methods of recording this information are indicated on the sample surveys at the end of this section.

When an extensive flood plain is encountered, it may be necessary to plot the entire cross section using a small scale and replot the low water portion of the channel to a larger scale so the more important features of this portion of the channel can be shown in more detail. An example of this method is shown in the samples at the end of this section.

A minimum of three cross sections is required at every crossing. Sections are required at each of the approximate upstream and downstream construction limits and a typical section of the downstream channel is required. Consideration

should be given to area, shape, channel material, and vegetation when choosing the location of the downstream typical section.

In addition to these required cross sections, other cross sections may be required to adequately describe the channel. If there is an existing bridge in place, a cross section should be taken beneath it. If there are any significant constrictions either upstream or downstream from the crossing, they should be defined with a cross section. Any major changes in channel shape, area, vegetation, or bottom material should also be cross sectioned.

Photographs of each cross section should be taken. Each should be well labeled to identify it. The photos should be taken at a time when the vegetation and channel will not be obscured by snow or ice.

2.17 PROFILES

The profiles are needed to determine the energy gradient of the channel and to aid in establishing the flow line elevations of the required structures. Two profiles are needed. The required profiles are: (1) a profile of the thalweg (a line describing the lowest point in the channel) and (2) a profile of the water surface. The thalweg profile of such rivers as the Missouri, Yellowstone, and Clark Fork are very difficult and may be omitted if an adequate water surface profile is taken.

The profiles should extend 1500 feet upstream and downstream from the proposed crossing. The profiles should be extended when necessary to incorporate ties to confluences with other streams, dams, or any other feature that could influence the proposed construction.

Whenever it is anticipated that a culvert will be necessary and that it will not be placed in the existing channel, a profile should be taken along the centerline of the proposed pipe. Whenever a channel change is necessary, a profile should also be provided along the centerline of the proposed channel changes. These profiles should be tied into the existing channel on both sides.

2.18 PLAN

The plan section serves two purposes: (1) the Hydraulics Unit uses it to determine some of the hydraulic features of the crossing and (2) the Bridge Bureau uses it to locate new bridge ends when a bridge is required.

This section needs to be filled out only for drainages of five square miles and larger unless it appears a bridge will be required.

The plan should show the detailed topography and contours of the immediate crossing area. The contours provide the most important information in this section. The contour interval should be chosen carefully so that good elevation detail is shown and so the plan does not become cluttered. The horizontal scale should be chosen as large as possible but small enough that all of the topography will still fit in the space provided.

2.19 EXAMPLES

FORM HYD 1

MONTANA DEPT OF HIGHWAYS

Survey Data for Design of Waterways

Project ______________________ No ________
Stream Name ______________________ Sta
County ______________
Surveyed By ______________ Date

FOR DRAINAGES OF ONE SQUARE MILE OR LARGER AND ALL IRRIGATION

GENERAL INSTRUCTIONS

1 Fill out all blanks carefully giving all information obtainable See Section 2 of the Hydraulics Manual for more detailed instructions, discussions, and examples
2 Make any comments or provide any additional information that you feel may be pertinent to the design of this crossing
3 Comments of local residents will aid in filling out much of this information The division lab may be of some help when filling out Section 3
4 The ditch rider, farmer, or ditch company should be contacted when filling out Section 4 Attach any right-of-way agreements if they have been made
5 Submit all survey notes with this sheet
6 Submit photographs of all channel and overbank areas and all existing structures Be sure they are well labeled Indicate the location and orientation of all photographs with an arrow(▷) in Section 8

SECTION 1 WATERSHED DATA

Estimated Drainage Area ______________ Acres or Sq Miles
Area not contributing to runoff ______________
Comment on land use or cover ______________

Floating Debris None ☐, Light ☐, Medium ☐, Heavy ☐
Other ☐, Quantity of Debris ______________
Ice Light ☐, Moderate ☐, Severe ☐.
Unusual Characteristics ______________

Elev of water on date of survey ______________
Elev of low water ______________, normally dry ☐
Elev of high water ______________, date occured ______________
Cause Backwater from ice ☐, Backwater from Construction ☐, Cloudburst ☐, Spring runoff ☐
Will ponding of water upstream cause damage to buildings or other property ______________ If so what elev will water be allowed to reach ______________
Should crossing be designed for fish passage ______________

SECTION 2 EXISTING STRUCTURE

A Culvert Size ________, Type ________
Condition ________ Length ________
B Bridge Type ______________
No of spans ________, Length of each span
________, ________, ________, ________
Clearance ______________
Condition ______________
C [illegible] distance above or below site ______________
Highwater mark elev ______________
Historical adequacy ______________

Comments ______________

SECTION 3 EROSION AND GEOLOGY DATA

Do banks or bed show scour? ________ is channel stable ☐, degrading ☐, agrading ☐, unknown ☐ Is riprap or bank protection necessary? ________
Are the following material available locally
Riprap ________, Type ________, Filter Material No 1 ________, No 2 ________
Is water or soil alkaline ________, acidic ________, are sulphates present ________
Comments ______________

SECTION 4 IRRIGATION DATA

Name of ditch ______________
Owner ______________
Address of ditch company ______________
Ditch capacity ________ Slope ________, Water Depth ________, Bottom width ________, Side Slopes ________, Total Depth ________
Does ditch carry flood water also? ________ Flow line elevations of existing structure, inlet ________ outlet ________

COMMENTS ______________

SECTION 5 LOCATION SKETCH (Scale 1" = 500')

Instructions Show ℄ of survey, north arrow, general course of stream, existing structures, location of all channel cross-sections shown in Section 6, and all general topography

SECTION 7 PROFILE

Instructions (A) Provide profiles of both the water surface and flowline of the existing channel for a minimum distance of 1500 ft up and downstream from the centerline Extend this profile when necessary to incorporate ties to natural or manmade features that will influence the proposed construction (B) Provide a profile along centerline of the proposed pipe when culvert will not be placed in existing channel and tie to natural stream channel (C) Provide profiles for proposed channel change, dikes, etc (D) Indicate scales

Horizontal 1" = ______
Vertical 1" = ______

SECTION 6 CROSS SECTIONS

Scale Horizontal 1" = ______ or as indicated ☐
Vertical 1" = ______ or as indicated ☐

Instructions Note cross-sections should embody the following general characteristics (1) Normal to channel (2) Section extremities to extend well above the maximum possible flood, (3) Vegetation described and accurately (±2) located, (4) Elevation differences of 6" or greater defined (5) Use scale of 1" = 10' vertical and horizontal unless there is an extensive flood plain In this case, a smaller horizonal scale may be used so as to define the flood plain and low water channel The low water portion should also be plotted again using a larger scale
(A) Provide typical section downstream from all proposed structures (B) Provide cross-section of approximate construction limits upstream and downstream from all proposed crossings (C) Provide section under existing bridges to include substructure details, spill-slopes, channel, and high water marks (D) Provide typical section of any irrigation ditches, etc that will be affected by the construction (E) Indicate location of each section in Section 5 and 8 (F) Attach photos of each section (G) When there is not enough room on this sheet plot addition cross-sections on a sheet of cross-section paper and attach it to this sheet

SECTION 8 PLAN

Instructions (A) Use scale 1" = 10', 1" = 20', or 1" = 50' depending on extent of field data (B) Indicate stationed centerline of survey (C) Draw contours with an interval as small as can be clearly shown (Contours are not necessary for irrigation) (D) Indicate elevation, location, and nature of damage that would result from flooding If overtopping of finish grade only, check here ☐ (E) Stream meander and edge of water on date of survey. (F) Indicate location of cross-sections shown in Section 6. (G) Indicate existing roads and structures (H) Indicate other features that may influence design

FORM HYD 1 Example No. 1 Intermediate Watershed

MONTANA DEPT OF HIGHWAYS

Survey Data for Design of Waterways

Project *Big Timber - Reedpoint* No *RF-127(7)*
Stream Name *Upper Deer Creek* Sta *343+86.5*
County *Sweetgrass*
Surveyed By *R.W. Solleman* Date *9-3-72*

FOR DRAINAGES OF ONE SQUARE MILE OR LARGER AND ALL IRRIGATION

GENERAL INSTRUCTIONS

1. Fill out all blanks carefully giving all information obtainable. See Section 2 of the Hydraulics Manual for more detailed instructions, discussions, and examples.
2. Make any comments or provide any additional information that you feel may be pertinent to the design of this crossing.
3. Comments of local residents will aid in filling out much of this information. The division lab may be of some help when filling out Section 3.
4. The ditch rider, farmer, or ditch company should be contacted when filling out Section 4. Attach any right-of-way agreements if they have been made.
5. Submit all survey notes with this sheet.
6. Submit photographs of all channel and overbank areas, and all existing structures. Be sure they are well labeled. Indicate the location and orientation of all photographs with an arrow (▷) in Section 8.

SECTION 1 WATERSHED DATA

Estimated Drainage Area *51* ~~Acres~~ or Sq Miles
Area not contributing to runoff *None*
Comment on land use or cover *1/3 Mountainous (60% Forest Cover), 1/2 Range land, 1/6 River bottom*
Floating Debris None ☐, Light ☐, Medium ☐, Heavy ☐
Other ☐, Quantity of Debris
Ice Light ☑, Moderate ☐, Severe ☐.
Unusual Characteristics *None*

Elev of water on date of survey *3964.0*
Elev of low water *3963.5*, normally dry ☐
Elev of high water *3972.0*, date occured *June 1967*
Cause Backwater from ice ☐, Backwater from Construction ☐, Cloudburst ☐, Spring runoff ☑
Will ponding of water upstream cause damage to buildings or other property *Yes* If so what elev will water be allowed to reach *3973.0*
Should crossing be designed for fish passage *Yes*
The elevations are measured at the upstream edge of the existing bridge

SECTION 2 EXISTING STRUCTURE

A Culvert Size ______, Type ______
Condition ______, Length ______
B Bridge Type *Steel and Concrete*
No of spans *1*, Length of each span *38'*
Clearance *8.5'*
Condition *Bridge-fair, Abutments-poor*
C Approx distance above or below the ______
Highwater mark elev *3967.0*
Historical adequacy *Washed out in 1967, see Comment below*
Comments

SECTION 3 EROSION AND GEOLOGY DATA

Do banks or bed show scour? *Yes*, is channel stable ☑, degrading ☐, agrading ☐, unknown ☐ Is riprap or bank protection necessary? *Yes*
Are the following material available locally
Riprap *Yes*, Type *A or B*, Filter Material No 1 *Yes*
No. 2 *Yes*
Is water or soil alkaline *No*, acidic *No*, are sulphates present *No*
Comments

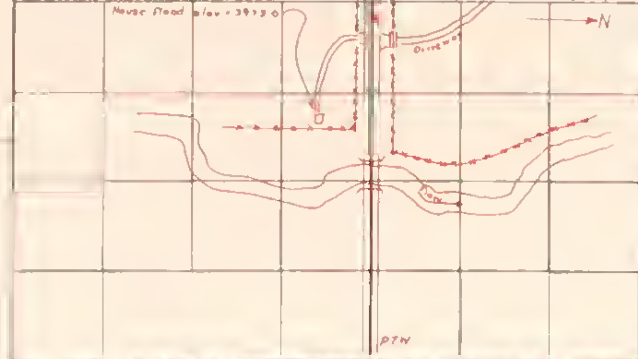
SECTION 4 IRRIGATION DATA

Name of ditch
Owner
Address of ditch company
Ditch capacity ______ Slope ______, Water Depth ______, Bottom width ______, Side Slopes ______, Total Depth ______
Does ditch carry flood water also? ______ Flow line elevations of existing structure, inlet ______ outlet ______

COMMENTS *Present structure has been adequate to handle the flow during normal runoff. A 5 1/2" rainfall in 48 hours, in June 1967, caused a flash flood that undermined the abutments of this bridge over US Highway #10. Debris blocking the inlet end of this structure was a partial cause of the failure. In the event of a flood such as in June, 1967 the present highway bridge could wash out again due to the heavy debris and down timber in the stream bed*

SECTION 5 LOCATION SKETCH (Scale 1" = 500')

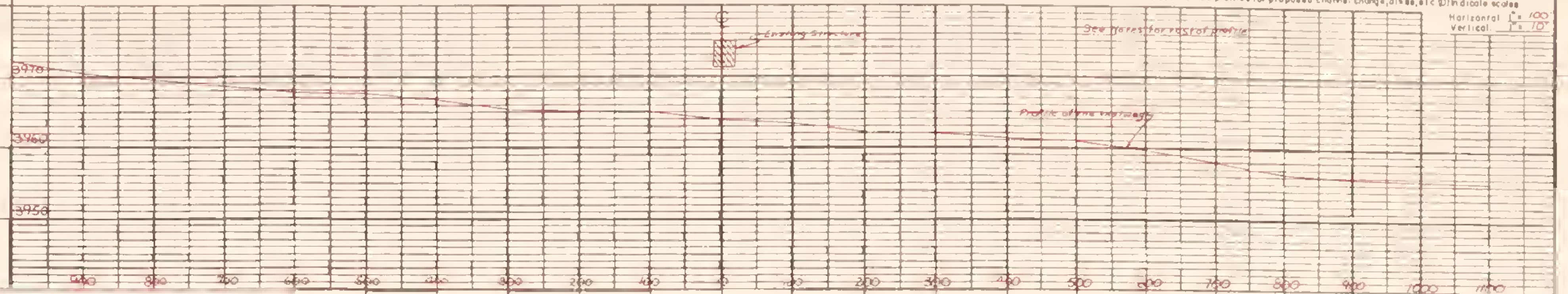
Instructions: Show ℄ of survey, north arrow, general course of stream, existing structures, location of all channel cross sections shown in Section 6, and all general topography



SECTION 7 PROFILE

Instructions (A) Provide profiles of both the water surface and flowline of the existing channel for a minimum distance of 1500 ft up and downstream from the centerline. Extend this profile when necessary to incorporate ties to natural or manmade features that will influence the proposed construction (B) Provide a profile along centerline of the proposed pipe when culvert is not be placed in existing channel and tie to natural stream channel (C) Provide profiles for proposed channel change, dikes, etc (D) Indicate scales

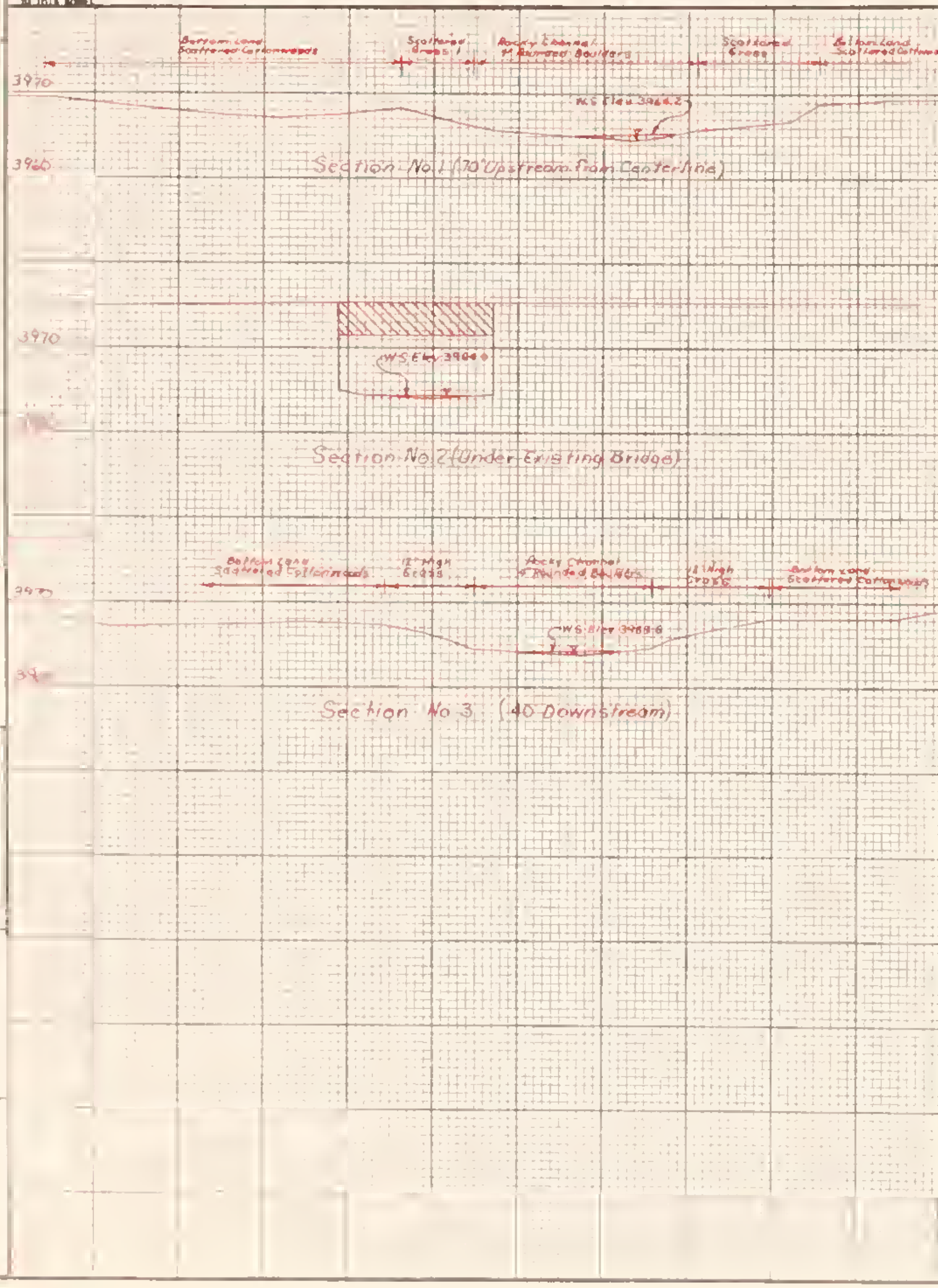
Horizontal 1" = 100'
Vertical 1" = 10'

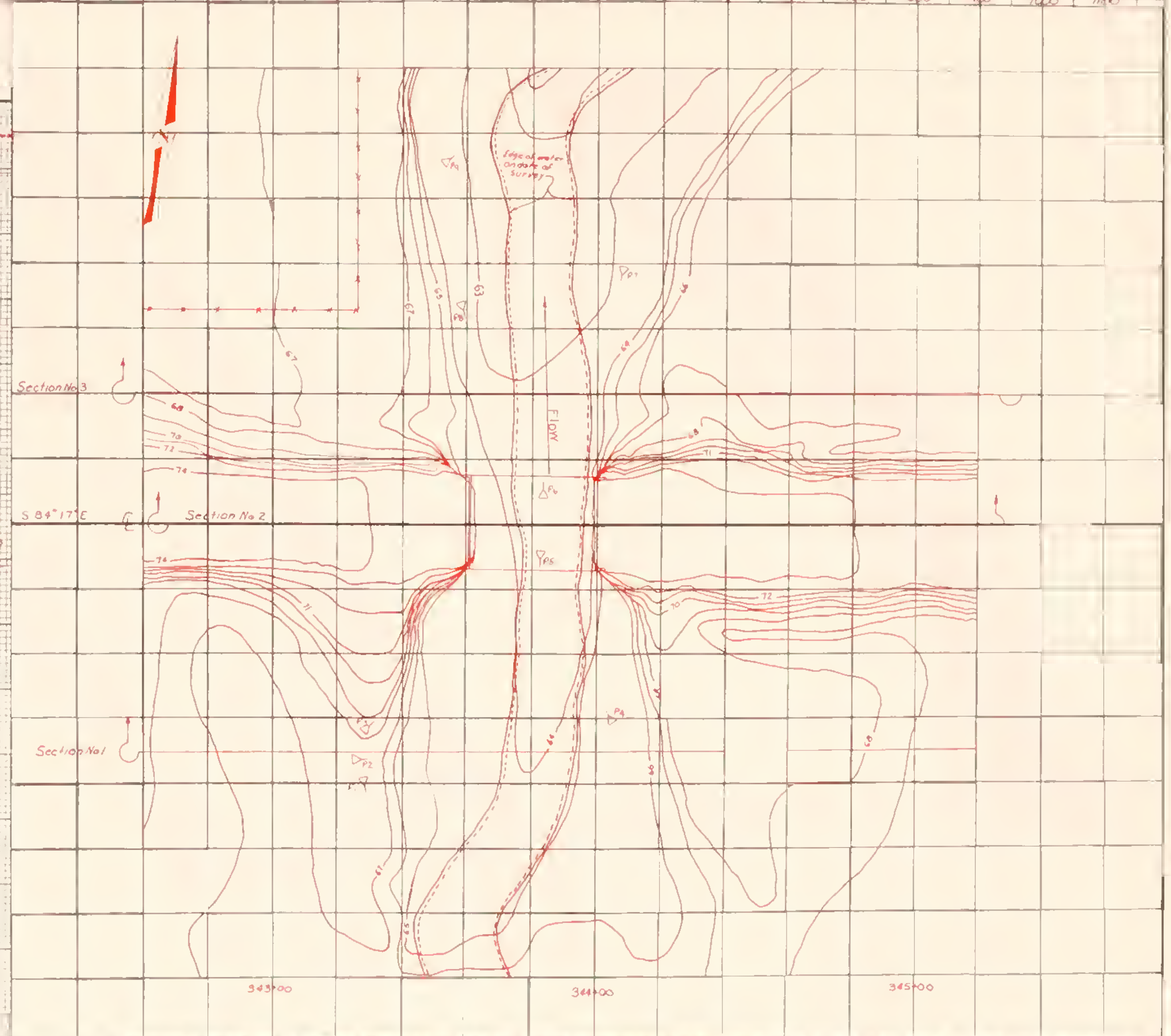


SECTION 6 CROSS SECTIONS

Scale Horizontal 1" = 20' ~~or as indicated☐~~
Vertical 1" = 10' ~~or as indicated☐~~

Instructions: Note, cross-sections should embody the following general characteristics, (1) Normal to channel, (2) Section extremities to extend well above the maximum possible flood, (3) Vegetation described and accurately (±2) located, (4) Elevation differences of 6" or greater defined, (5) Use scale of 1" = 10' vertical and horizontal unless there is an extensive flood plain in this case, a smaller horizontal scale may be used so as to define the flood plain and low water channel. The low water portion should also be plotted again using a larger scale.
(A) Provide typical section downstream from all proposed structures (B) Provide cross-section at approximate construction limits upstream and downstream from all proposed crossings (C) Provide section under existing bridges to include substructure details, spill-slopes, channel, and high water marks (D) Provide typical section of any irrigation ditches, etc that will be affected by the construction (E) Indicate location of each section in Section 5 and 8 (F) Attach photos of each section (G) When there is not enough room on this sheet plot addition cross-sections on a sheet of cross-section paper and attach it to this sheet





SECTION 8 PLAN

Instructions (A) Use scale 1" = 10', or 1" = 50' depending on extent of field data (B) Indicate stationed centerline of survey (C) Draw contours with an interval as small as can be clearly shown (Contours are not necessary for irrigation) (D) Indicate elevation, location, and nature of damage that would result from flooding. If overtopping of finish grade only, check here ☐ (E) Stream meander and edge of water on date of survey (F) Indicate location of cross-sections shown in Section 6 (G) Indicate existing roads and structures (H) Indicate other features that may influence design

FORM HYD 1 Example No 2 Large Watershed

MONTANA DEPT OF HIGHWAYS

Survey Data for Design of Waterways

Project St Regis E&W No I-90-1(13)27
Stream Name Clark Fork River Sta 658+00
County Mineral
Surveyed By TO+H Inc Date 7-2-68

FOR DRAINAGES OF ONE SQUARE MILE OR LARGER AND ALL IRRIGATION

GENERAL INSTRUCTIONS

1 Fill out all blanks carefully giving all information obtainable See Section 2 of the Hydraulics Manual for more detailed instructions, discussions, and examples
2 Make any comments or provide any additional information that you feel may be pertinent to the design of this crossing
3 Comments of local residents will aid in filling out much of this information The division lab may be of some help when filling out Section 3
4 The ditch rider, farmer, or ditch company should be contacted when filling out Section 4 Attach any right-of-way agreements if they have been made
5 Submit all survey notes with this sheet
6 Submit photographs of all channel and overbank areas, and all existing structures Be sure they are well labeled Indicate the location and orientation of all photographs with an arrow (▷→) in Section 8

SECTION 1 WATERSHED DATA

Estimated Drainage Area 10,000 Acres or Sq Miles
Area not contributing to runoff Negligible
Comment on land use or cover Mountainous

Floating Debris None ☐, Light ☐, Medium ☐, Heavy ☐
Other ☐, Quantity of Debris
Ice Light ☐, Moderate ☐, Severe ☐,
Unusual Characteristics None

Elev of water on date of survey 2609 5
Elev of low water 2608 1, normally dry ☐
Elev of high water 2620.1, date occured 5-9 1948
Cause Backwater from ice ☐, Backwater from Construction ☐, Cloudburst ☐, Spring runoff ☐
Will ponding of water upstream cause damage to buildings or other property No If so what elev will water be allowed to reach —
Should crossing be designed for fish passage Yes

SECTION 2 EXISTING STRUCTURE

A Culvert Size , Type
Condition , Length
B Bridge Type Concrete and Truss Girders
No of spans 7, Length of each span
20, 42, 65, 57, 175, 225, 5
Clearance 35 6'
Condition Good
350 Below site
Highwater mark elev 2610 9
Historical adequacy Very Adequate

Comments

SECTION 3 EROSION AND GEOLOGY DATA

Do banks or bed show scour? No, is channel stable ☐, degrading ☐, agrading ☐, unknown ☐ Is riprap or bank protection necessary? No
Are the following material available locally
Riprap Yes, Type B, Filter Material No 1 Yes, No. 2 Yes
Is water or soil alkaline No, acidic No, are sulphates present No
Comments

SECTION 4 IRRIGATION DATA

Name of ditch
Owner
Address of ditch company
Ditch capacity , Slope , Water Depth , Bottom width , Side Slopes , Total Depth
Does ditch carry flood water also? Flow line elevations of existing structure, inlet outlet

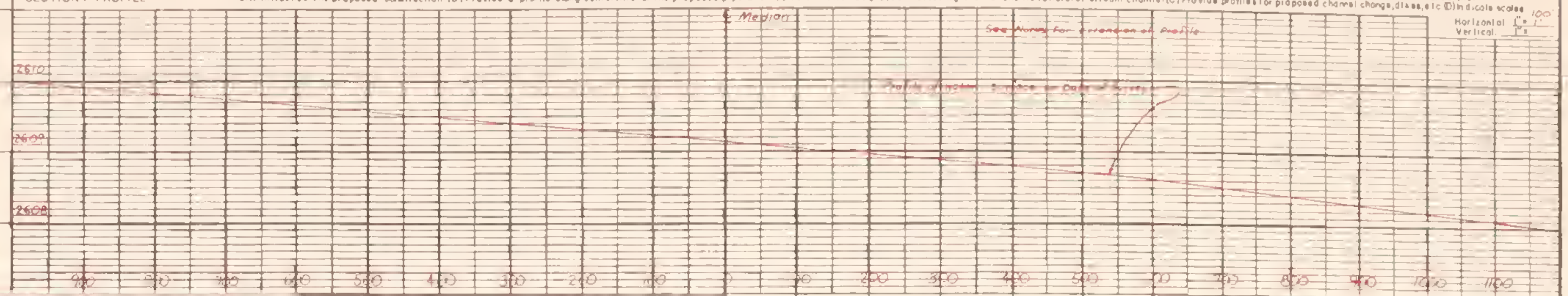
COMMENTS
Uniformity of the channel and cross section adequately described this crossing Neither the RR or the railroad present any constriction

SECTION 5 LOCATION SKETCH (Scale 1" = 500')

Instructions Show ℄ of survey, north arrow, general course of stream, existing structures, location of all channel cross-sections shown in Section 6, and all general topography.

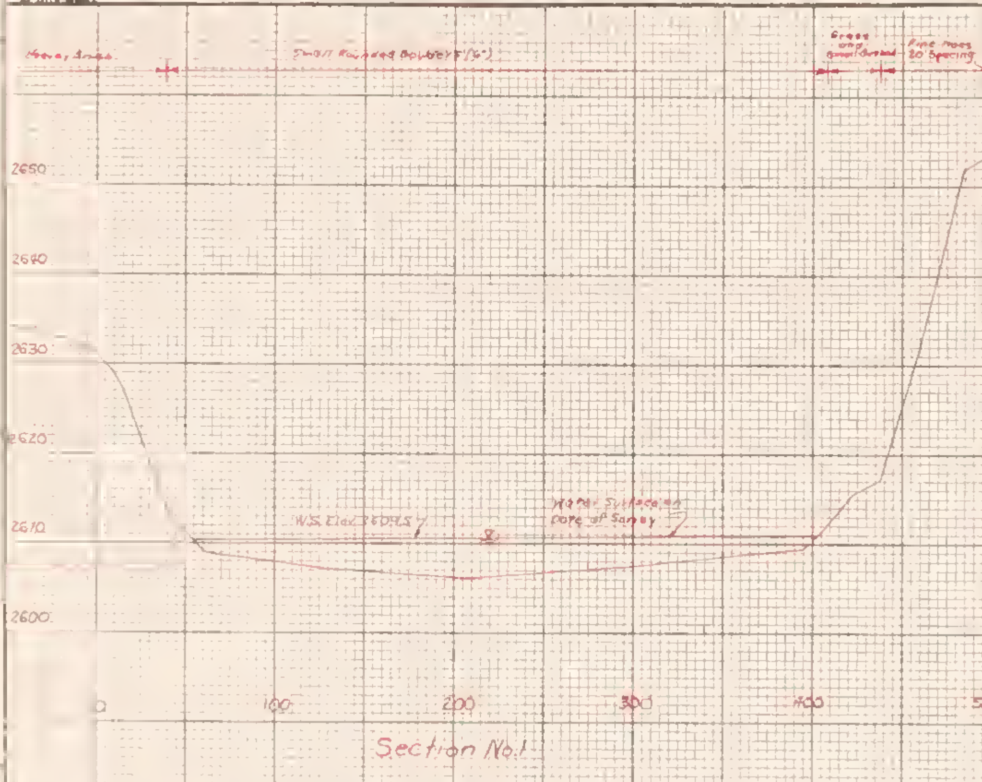
SECTION 7 PROFILE

Instructions (A) Provide profiles of both the water surface and flowline of the existing channel for a minimum distance of 1500 ft up and downstream from the centerline Extend this profile when necessary to incorporate the natural or manmade features that will influence the proposed construction (B) Provide a profile along centerline of the proposed pipe when culvert will not be placed in existing channel and its natural stream channel (C) Provide profiles for proposed channel change, dikes, etc (D) Indicate scales Horizontal 1" = 100' Vertical 1" =

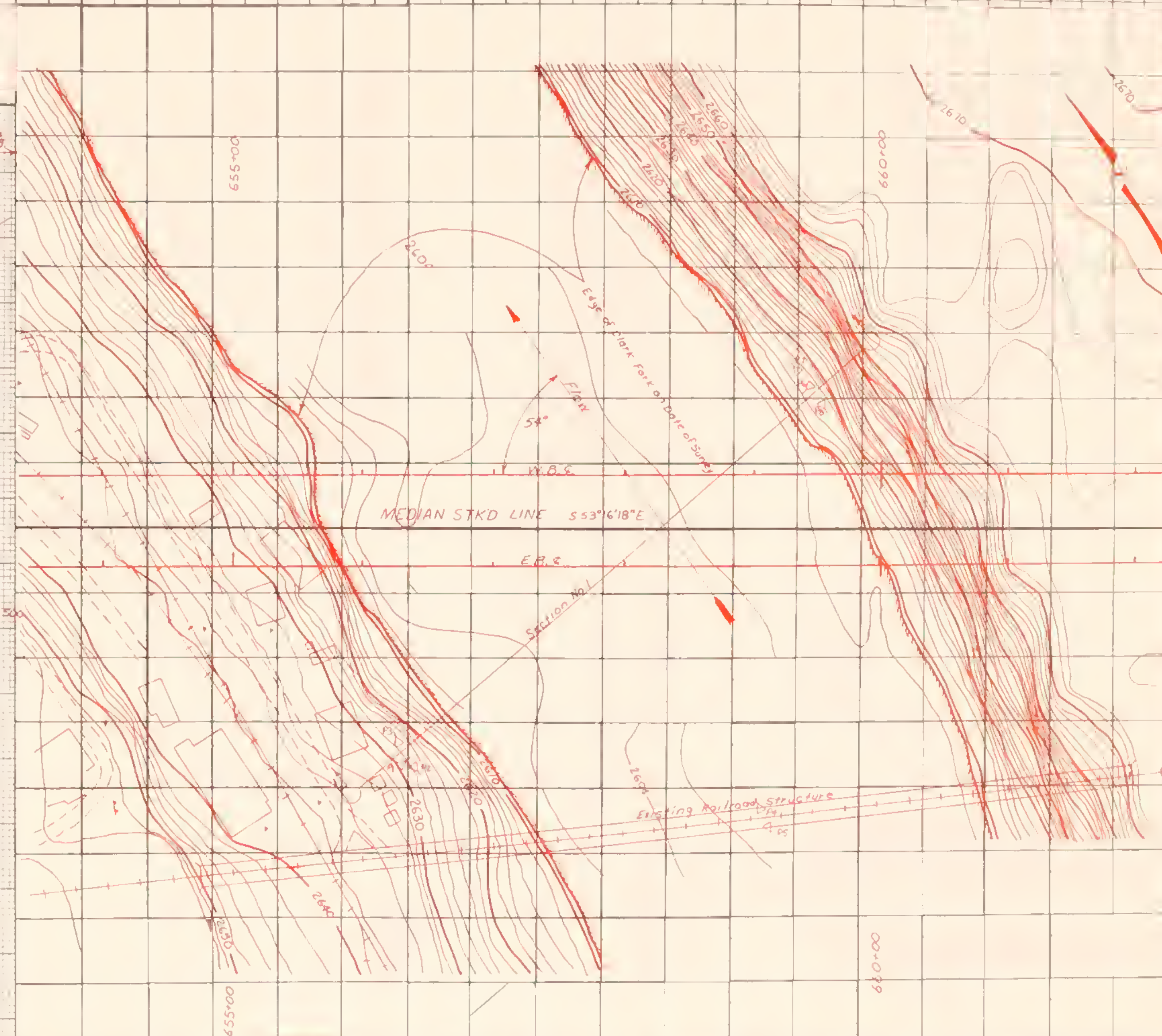


SECTION 6 CROSS SECTIONS Scale Horizontal 1" = 10 or as indicated ☐ Vertical 1" = or as indicated ☐

Instructions Note, cross-sections should embody the following general characteristics, (1) Normal to channel, (2) Section extremities to extend well above the maximum possible flood, (3) Vegetation described and accurately (±2) located, (4) Elevation differences of 6" or greater defined (5) Use scale of 1" = 10' vertical and horizontal unless there is an extensive flood plain in this case, a smaller horizontal scale may be used so as to define the flood plain and low water channel. The low water portion should also be plotted again using a larger scale
(A) Provide typical section downstream from all proposed structures (B) Provide cross-section at approximate construction limits upstream and downstream from all proposed crossings (C) Provide section under existing bridges to include substructure details, spill-slopes, channel, and high water marks (D) Provide typical section of any irrigation ditches, etc that will be affected by the construction (E) Indicate location of each section in Section 5 and 8 (F) Attach photos of each section (G) When there is not enough room on this sheet plot addition cross-sections on a sheet of cross-section paper and attach it to this sheet



Section No.1



SECTION 8 PLAN Instructions (A) Use scale 1" = 10', 1" = 20', or 1" = 50' depending on extent of field data (B) Indicate stationed centerline of survey (C) Draw contours with an interval as small as can be clearly shown (Contours are not necessary for irrigation) (D) Indicate elevation, location, and nature of damage that would result from flooding If overtopping of finish grade only, check here ☐ (E) Stream meander and edge of water on date of survey (F) Indicate location of cross-sections shown in Section 6 (G) Indicate existing roads and structures (H) Indicate other features that may influence design

FORM HYD Example No. 3 Large Watershed

MONTANA DEPT OF HIGHWAYS

Survey Data for Design of Waterways

Project *Biddle-East* No *S-460(3)*
Stream Name *Little Powder River* Sta *21+50*
County *Powder River*
Surveyed By *C.W. Taylor* Date *1-29-70*

FOR DRAINAGES OF ONE SQUARE MILE OR LARGER AND ALL IRRIGATION

GENERAL INSTRUCTIONS

1. Fill out all blanks carefully giving all information obtainable. See Section 2 of the Hydraulics Manual for more detailed instructions, discussions and examples.
2. Make any comments or provide any additional information that you feel may be pertinent to the design of this crossing.
3. Comments of local residents will aid in filling out much of this information. The division lab may be of some help when filling out Section 3.
4. The ditch rider, farmer, or ditch company should be contacted when filling out Section 4. Attach any right-of-way agreements if they have been made.
5. Submit all survey notes with this sheet.
6. Submit photographs of all channel and overbank areas, and all existing structures. Be sure they are well labeled. Indicate the location and orientation of all photographs with an arrow (▷) in Section 8.

SECTION 1 WATERSHED DATA

Estimated Drainage Area *1500* ~~Acres~~ or Sq Miles
Area not contributing to runoff *None*
Comment on land use or cover *99% Rangeland*

Floating Debris: None ☐, Light ☑, Medium ☐, Heavy ☐
Other ☐, Quantity of Debris ______
Ice: Light ☐, Moderate ☑, Severe ☐
Unusual Characteristics *None*

Elev of water on date of survey *3250.9*
Elev of low water *3249.8* normally dry ☐
Elev of high water *3256.9*, date occurred *?*
Cause: Backwater from ice ☐, Backwater from Construction ☐, Cloudburst ☐, Spring runoff ☑
Will ponding of water upstream cause damage to buildings or other property *Yes*. If so what elev will water be allowed to reach *3261.5*
Should crossing be designed for fish passage *No*

SECTION 2 EXISTING STRUCTURE

A. Culvert Size ______, Type ______
Condition ______, Length ______
B. Bridge Type *Steel Truss*
No of spans *1*, Length of each span *103*
Clearance *22.5*
Condition *Poor*
C. Approx distance above or below site
Highwater mark elev *3257.9*
Historical adequacy *This crossing has always been adequate.*
Comments ______

SECTION 3 EROSION AND GEOLOGY DATA

Do banks or bed show scour? *No*, is channel stable ☑, degrading ☐, agrading ☐, unknown ☐. Is riprap or bank protection necessary? *Yes*
Are the following material available locally:
Riprap *Yes*, Type *A*, Filter Material No 1 *No*, No 2 *No*
Is water or soil alkaline *Yes*, acidic *No*, are sulphates present *No*
Comments ______

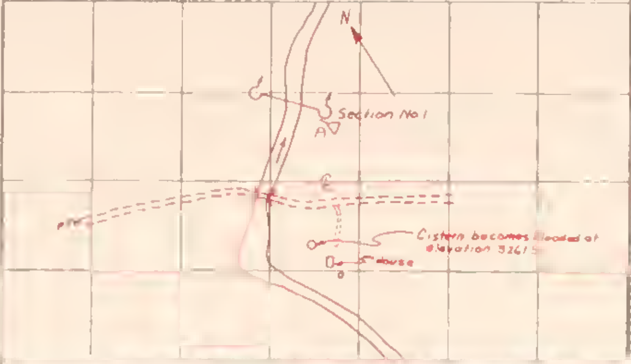
SECTION 4 IRRIGATION DATA

Name of ditch ______
Owner ______
Address of ditch company ______
Ditch capacity ______, Slope ______, Water Depth ______, Bottom width ______, Side Slopes ______, Total Depth ______
Does ditch carry flood water also? ______ Flow line elevations of existing structure, inlet ______ outlet ______

COMMENTS *This river dried up completely in August, 1967.*

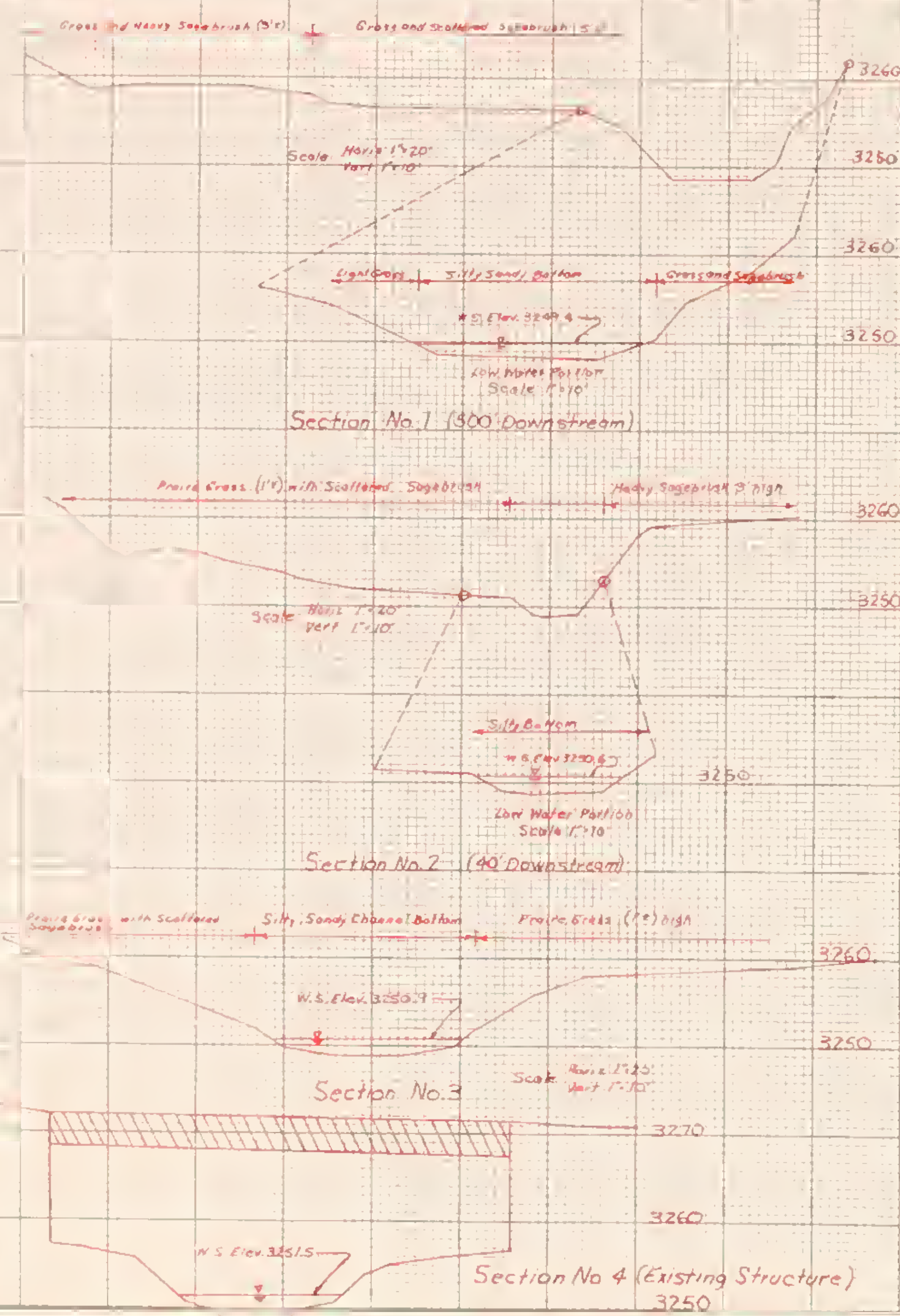
SECTION 5 LOCATION SKETCH (Scale 1" = 500')

Instructions: Show ℄ of survey, north arrow, general course of stream, existing structures, location of all channel cross sections shown in Section 6, and all general topography.



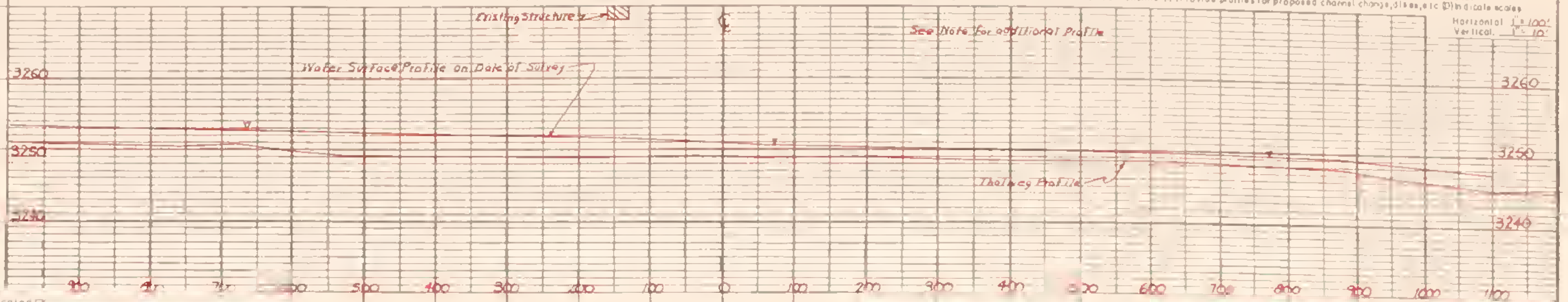
SECTION 6 CROSS SECTIONS Scale Horizontal ____ as indicated ☑ Vertical ____ as indicated ☑

Instructions: Note: cross-sections should embody the following general characteristics: (1) Normal to channel, (2) Section extremities to extend well above the maximum possible flood, (3) Vegetation described and accurately located, (4) Elevation differences of 6" or greater defined, (5) Use scale of 1" = 10' vertical and horizontal unless there is an extensive flood plain. In this case, a smaller horizontal scale may be used so as to define the flood plain and low water channel. The low water portion should also be plotted again using a larger scale.
(A) Provide typical section downstream from all proposed structures. (B) Provide cross section at approximate construction limits upstream and downstream from all proposed crossings. (C) Provide section under existing bridges to include substructure details, spill slopes, channel and high water marks. (D) Provide typical section of any irrigation ditches etc. that will ... Attach photos of each section. (G) When there is not enough room on this sheet plot addition cross sections on a sheet of cross-section paper and attach it to this sheet.

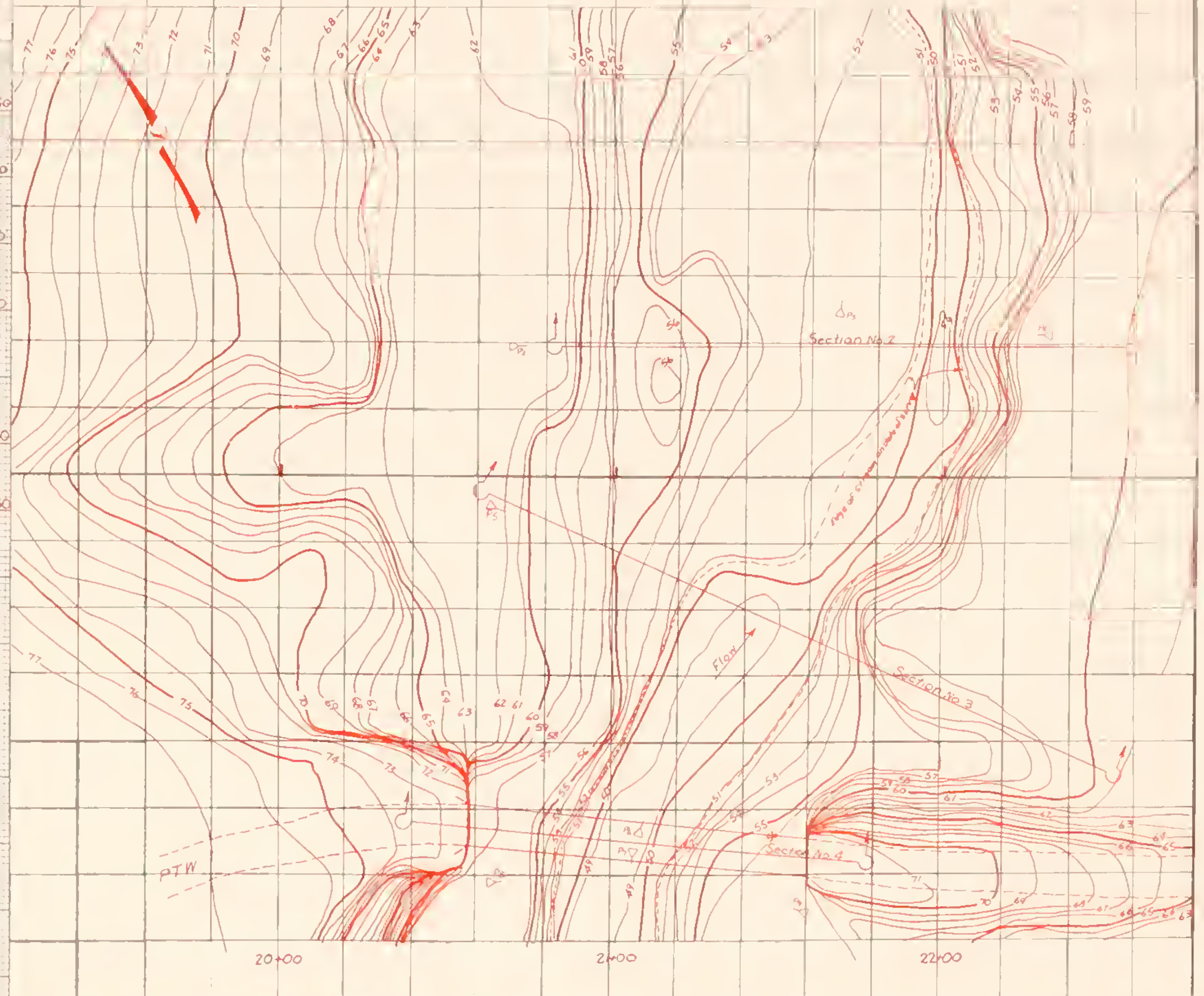


SECTION 7 PROFILE

Instructions: (A) Provide profiles of both the water surface and flowline of the existing channel for a minimum distance of 300'± up and downstream from the centerline. Extend this profile when necessary to incorporate features natural or manmade features that will influence the proposed construction. (B) Provide a profile along centerline of the proposed pipe when culvert will not be placed in existing channel and lie to natural stream channel. (C) Provide profiles for proposed channel change, dikes, etc. (D) Indicate scales.



SECTION 8 PLAN



Instructions: (A) Use scale ~~1"=10'~~, 1" = 20', ~~or 1"=50'~~ depending on extent of field data. (B) Indicate stationed centerline of survey. (C) Draw contours with an interval as small as can be clearly shown. (Contours are not neccessary for irrigation) (D) Indicate elevation, location, and nature of damage that would result from flooding. If overtopping of finish grade only, check here ☐. (E) Stream meander and edge of water on date of survey. (F) Indicate location of cross-sections shown in Section 6. (G) Indicate existing roads and structures. (H) Indicate other features that may influence design.

FORM HYD 1

Example No. 4 Small Watershed

MONTANA DEPT OF HIGHWAYS

Survey Data for Design of Waterways

Project *Turner-South* No. *S-241(6)*
Stream Name *Bell Coulee* Sta. *119+50*
County *Blaine*
Surveyed By *R.L. Kirschman* Date *4-9-73*

FOR DRAINAGES OF ONE SQUARE MILE OR LARGER AND ALL IRRIGATION

GENERAL INSTRUCTIONS

1. Fill out all blanks carefully giving all information obtainable. See Section 2 of the Hydraulics Manual for more detailed instructions, discussions, and examples.
2. Make any comments or provide any additional information that you feel may be pertinent to the design of this crossing.
3. Comments of local residents will aid in filling out much of this information. The division lab may be of some help when filling out Section 3.
4. The ditch rider, farmer, or ditch company should be contacted when filling out Section 4. Attach any right-of-way agreements if they have been made.
5. Submit all survey notes with this sheet.
6. Submit photographs of all channel and overbank areas and of existing structures. Be sure they are well labeled. Indicate the location and orientation of all photographs with an arrow (▷) in Section 8.

SECTION 1 WATERSHED DATA

Estimated Drainage Area *1500* Acres ~~or Sq Miles~~
Area not contributing to runoff *None*
Comment on land use or cover *90% Dry Land wheat*

Floating Debris: None ☐, Light ☑, Medium ☐, Heavy ☐
Other ☐, Quantity of Debris ____
Ice: Light ☑, Moderate ☐, Severe ☐.
Unusual Characteristics ____

Elev of water on date of survey *Dry*
Elev of low water *—*, normally dry ☑
Elev of high water *?*, date occured ____
Cause: Backwater from ice ☐, Backwater from Construction ☐, Cloudburst ☑, Spring runoff ☐
Will ponding of water upstream cause damage to buildings or other property *No*. If so what elev will water be allowed to reach *—*
Should crossing be designed for fish passage *No*

SECTION 2 EXISTING STRUCTURE *None*

A. Culvert Size ____, Type ____
Condition ____, Length ____

B. Bridge Type ____
No of spans ____, Length of each span ____
Clearance ____
Condition ____

Highwater mark elev ____
Historical adequacy ____

Comments ____

SECTION 3 EROSION AND GEOLOGY DATA

Do banks or bed show scour? *Yes*, is channel stable ☐, degrading ☑, agrading ☐, unknown ☐. Is riprap or bank protection necessary? *Yes*

Are the following material available locally:
Riprap *Yes*, Type *B & A*, Filter Material No. 1 *Yes*, No. 2 *Yes*

Is water or soil alkaline *No*, acidic *No*, are sulphates present *No*

Comments ____

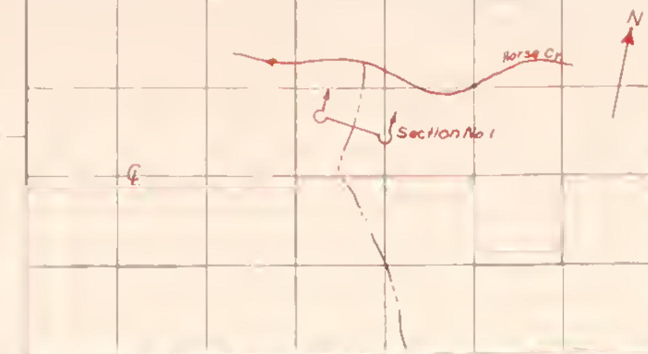
SECTION 4 IRRIGATION DATA

Name of ditch ____
Owner ____
Address of ditch company ____
Ditch capacity ____, Slope ____, Water Depth ____, Bottom width ____, Side Slopes ____, Total Depth ____
Does ditch carry flood water also? ____ Flow line elevations of existing structure, inlet ____ outlet ____

COMMENTS ____

SECTION 5 LOCATION SKETCH (Scale 1"=500')

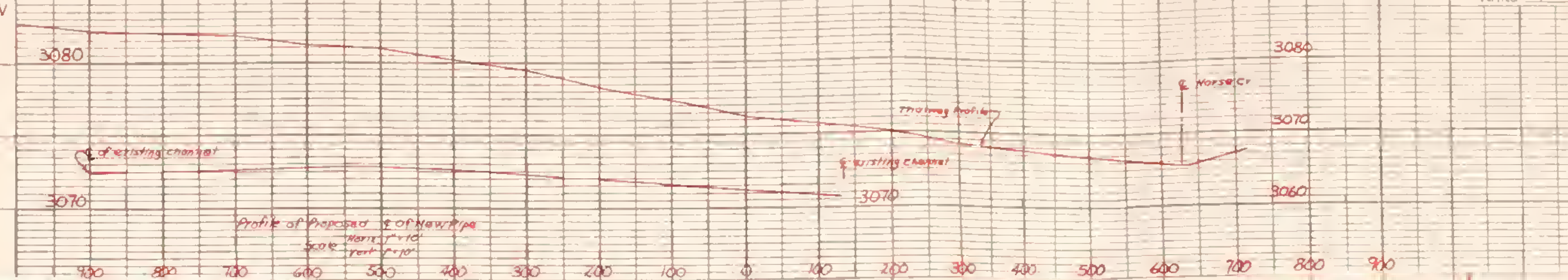
Instructions: Show ℄ of survey, north arrow, general course of stream, existing structures, location of all channel cross sections shown in Section 6, and all general topography.



SECTION 7 PROFILE

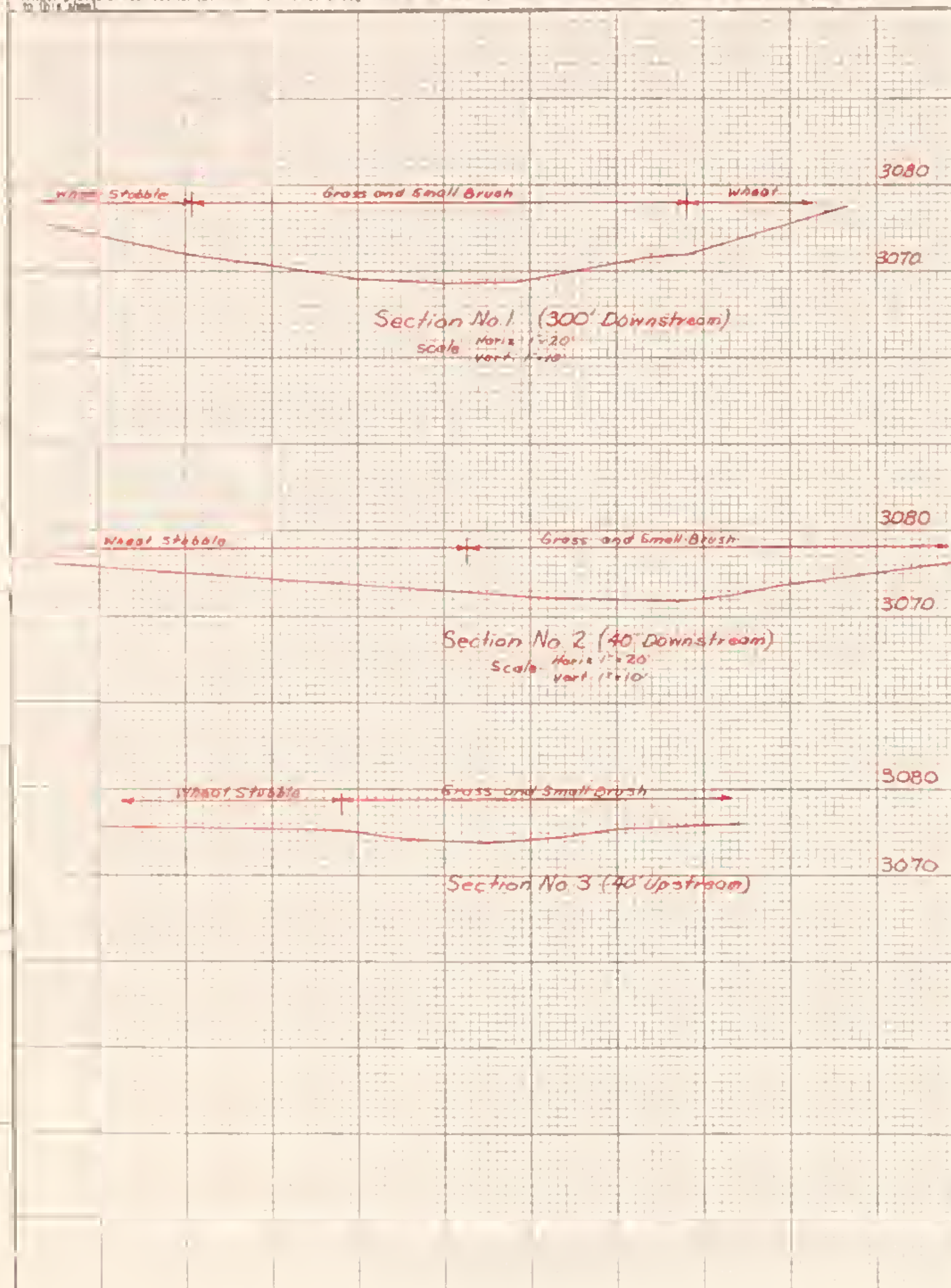
Instructions: (A) Provide profiles of both the water surface and flowline of the existing channel for a minimum distance of 1500 ft up and downstream from the centerline. Extend this profile when necessary to incorporate lies to natural or manmade features that will influence the proposed construction. (B) Provide a profile along centerline of the proposed pipe when culvert will not be placed in existing channel and lie to natural stream channel. (C) Provide profiles for proposed channel changes, dikes, etc. (D) Indicate scales.

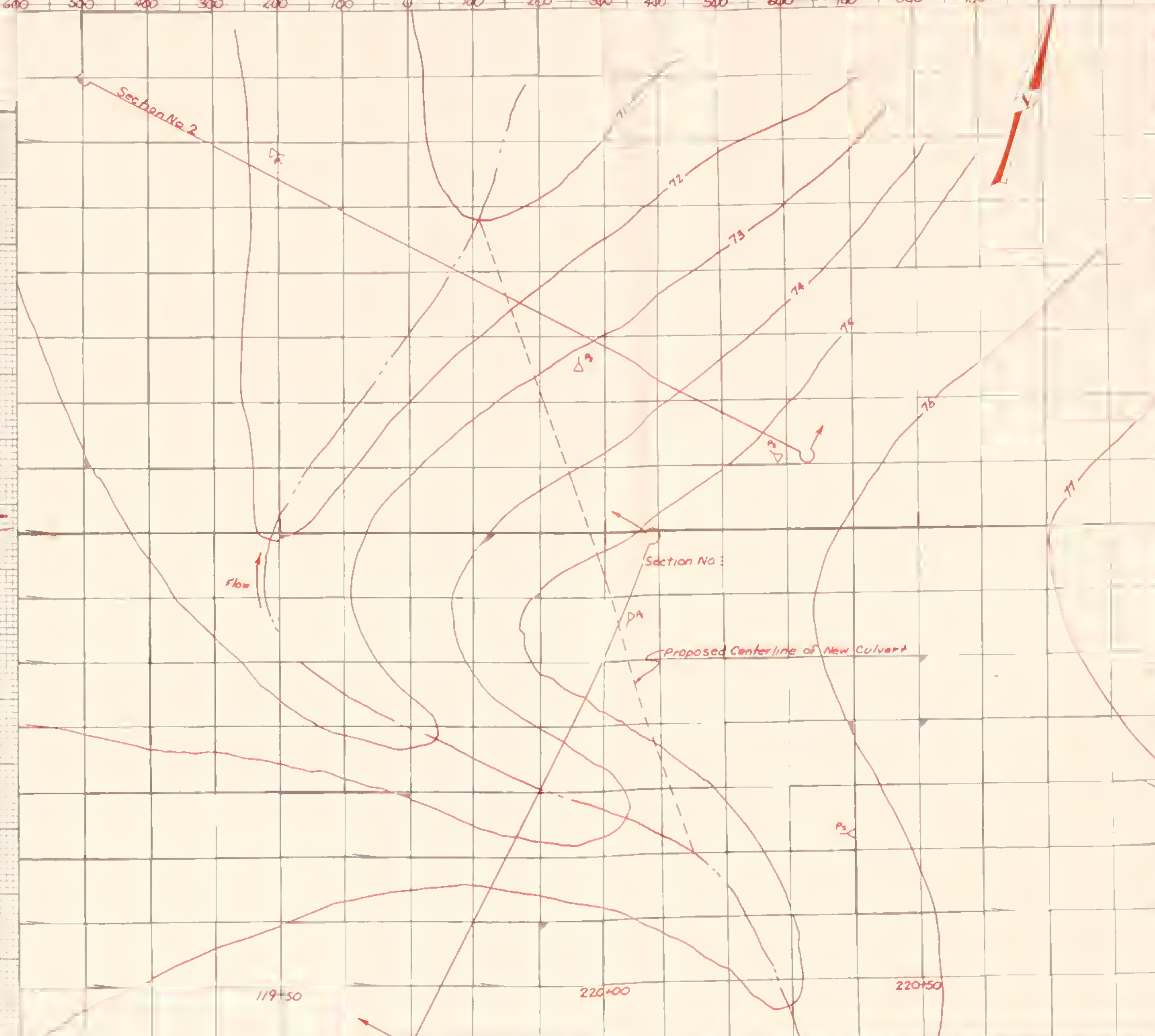
Horizontal 1"=100'
Vertical 1"=10'



SECTION 6 CROSS SECTIONS Scale Horizontal ~~1"=~~ or as indicated ☑
Vertical 1"=10' ~~or as indicated~~ ☐

Instructions: Note: Cross sections should embody the following general characteristics: (1) Normal to channel, (2) Section extremities to extend well above the maximum possible flood, (3) Vegetation described and accurately located, (4) Elevation differences of 6" or greater defined, (5) Use scale of 1"=10' vertical and horizontal unless there is an extensive flood plain. In this case, a smaller horizontal scale may be used so as to define the flood plain and low water channel. The low water portion should also be plotted again using a larger scale.
(A) Provide typical section downstream from all proposed structures. (B) Provide cross-section at approximate construction limits upstream and downstream from all proposed crossings. (C) Provide section under existing bridges to include substructure details, spill-slopes, channel and high water marks. (D) Provide typical section of any irrigation ditches, etc. that will be affected by the construction. (E) Indicate location of each section in Section 5 and 8. (F) Attach photos of each section. (G) When there is not enough room on this sheet plot additional cross sections on a sheet of cross section paper and attach it to this sheet.





SECTION 8 PLAN

Instructions: (A) Use scale 1"=10', 1"=20', or 1"=50' depending on extent of field data. (B) Indicate stationed centerline of survey. (C) Draw contours with an interval as small as can be clearly shown. (Contours are not necessary for irrigation) (D) Indicate elevation, location, and nature of damage that would result from flooding if overtopping of finish grade only, check here ☐ (E) Stream meander and edge of water on date of survey (F) Indicate location of cross-sections shown in Section 6. (G) Indicate existing roads and structures (H) Indicate other features that may influence design.

FORM HYD 1 **Example No. 5 Small Watershed**

MONTANA DEPT OF HIGHWAYS

Survey Data for Design of Waterways

Project: Circle-North No: S-43(19)
Stream Name: 12 Mile Cr. Sta: 318+65
County: McCone
Surveyed By: Warren Fenstroll Date: 8-11-73

FOR DRAINAGES OF ONE SQUARE MILE OR LARGER AND ALL IRRIGATION

GENERAL INSTRUCTIONS

1. Fill out all blanks carefully giving all information obtainable. See Section 2 of the Hydraulics Manual for more detailed instructions, discussions, and examples.
2. Make any comments or provide any additional information that you feel may be pertinent to the design of this crossing.
3. Comments of local residents will aid in filling out much of this information. The division lab may be of some help when filling out Section 3.
4. The ditch rider, farmer, or ditch company should be contacted when filling out Section 4. Attach any right-of-way agreements if they have been made.
5. Submit all survey notes with this sheet.
6. Submit photographs of all channel and overbank areas, and all existing structures. Be sure they are well labeled. Indicate the location and orientation of all photographs with an arrow (▷) in Section 8.

SECTION 1 WATERSHED DATA

Estimated Drainage Area: 12.5 ~~Acres or~~ Sq Miles
Area not contributing to runoff: None
Comment on land use or cover: Prairie and Rangeland etc's

Floating Debris: None ☐, Light ☑, Medium ☐, Heavy ☐
Other ☐, Quantity of Debris ____
Ice: Light ☑, Moderate ☐, Severe ☐.
Unusual Characteristics: There is a stock dam ½ mile upstream. See comments below.
Elev of water on date of survey: Dry
Elev of low water: —, normally dry ☑
Elev of high water: 2583±, date occured: 1964
Cause: Backwater from ice ☐, Backwater from Construction ☐, Cloudburst ☑, Spring runoff ☐
Will ponding of water upstream cause damage to buildings or other property: No. If so what elev will water be allowed to reach: No
Should crossing be designed for fish passage: No

SECTION 2 EXISTING STRUCTURE

A. Culvert: Size 96", Type SSPP
Condition: Good, Length 80'
B. Bridge: Type ____
No of spans ____, Length of each span ____
Clearance ____
Condition ____
C. Approx distance above or below site: [illegible]
Highwater mark elev: 2583±
Historical adequacy: The pipe has been adequate although the water has approached the top of the
Comments: roadway a number of times.

SECTION 3 EROSION AND GEOLOGY DATA

Do banks or bed show scour? Yes, is channel stable ☐, degrading ☐, agrading ☐, unknown ☑. Is riprap or bank protection necessary? Yes
Are the following material available locally:
Riprap: Yes, Type: Rock, Filter Material No 1: Yes, No. 2: Yes
Is water or soil alkaline: No, acidic: No, are sulphates present: No
Comments ____

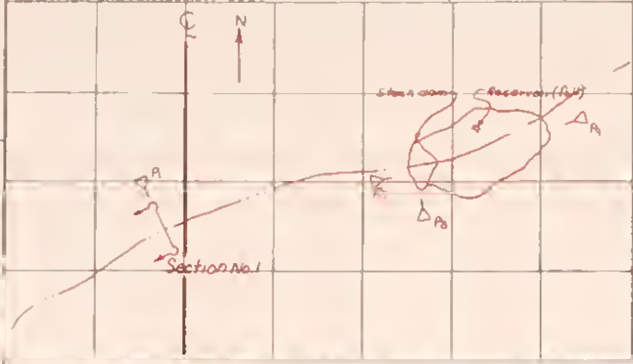
SECTION 4 IRRIGATION DATA

Name of ditch ____
Owner ____
Address of ditch company ____
Ditch capacity ____, Slope ____, Water Depth ____, Bottom width ____, Side Slopes ____, Total Depth ____
Does ditch carry flood water also? ____ Flow line elevations of existing structure, inlet ____ outlet ____

COMMENTS: There is a stock dam ½ mile upstream. It was built and is owned by Ral White of Rural Route 2, Circle. It is a 10' high earth fill dam. The reservoir when full is approx. 5 acres in size. There is no outlet pipe and no spillway. The dam does show signs of washing. See photos.

SECTION 5 LOCATION SKETCH (Scale 1" = 500')

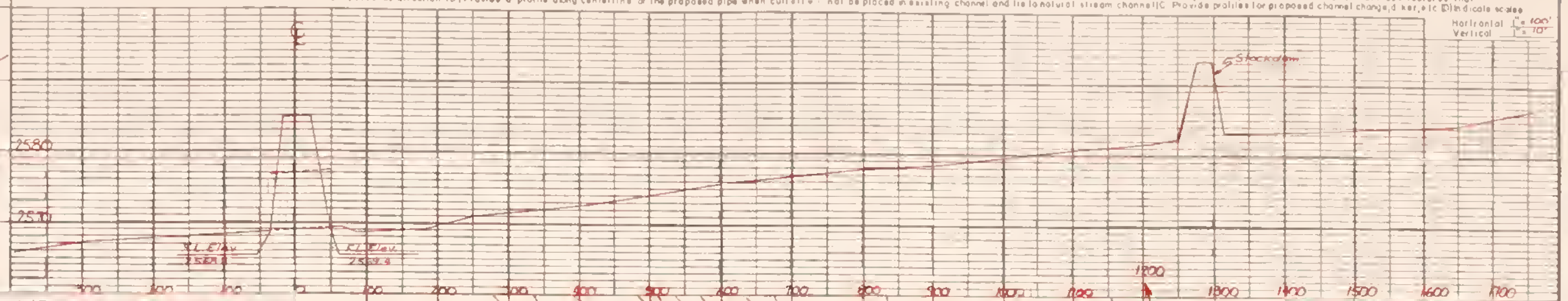
Instructions: Show ℄ of survey, north arrow, general course of stream, existing structures, location of all channel cross sections shown in Section 6, and all general topography.



SECTION 7 PROFILE

Instructions: (A) Provide profiles of both the water surface and flowline of the existing channel for a minimum distance of 1500 ft up and downstream from the centerline. Extend this profile when necessary to incorporate longitudinal or manmade features that will influence the proposed construction. (B) Provide a profile along centerline of the proposed pipe when culvert will not be placed in existing channel and its longitudinal stream channel. (C) Provide profiles for proposed channel change, dikes, etc. (D) Indicate scales.

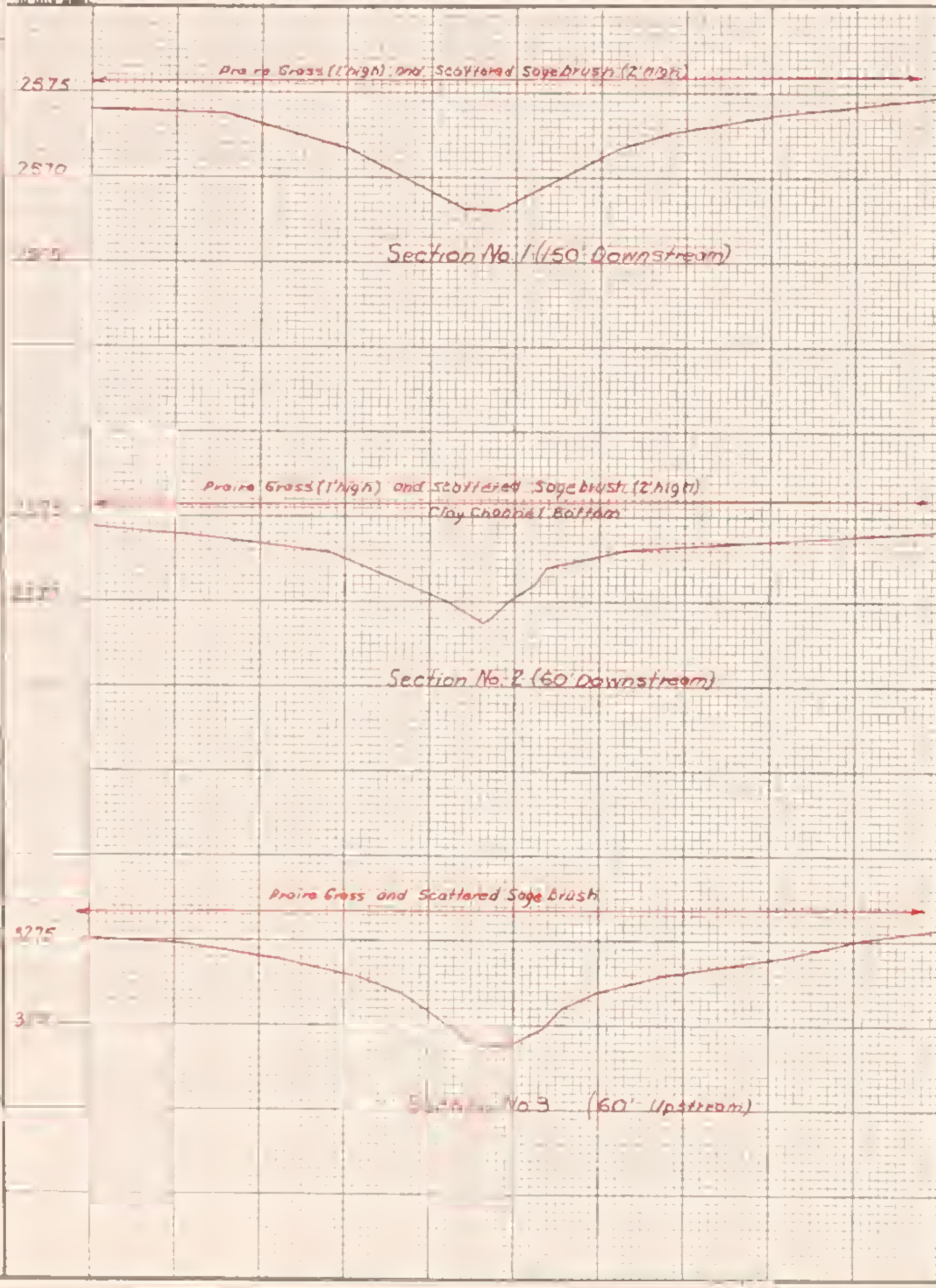
Horizontal 1" = 100'
Vertical 1" = 10'



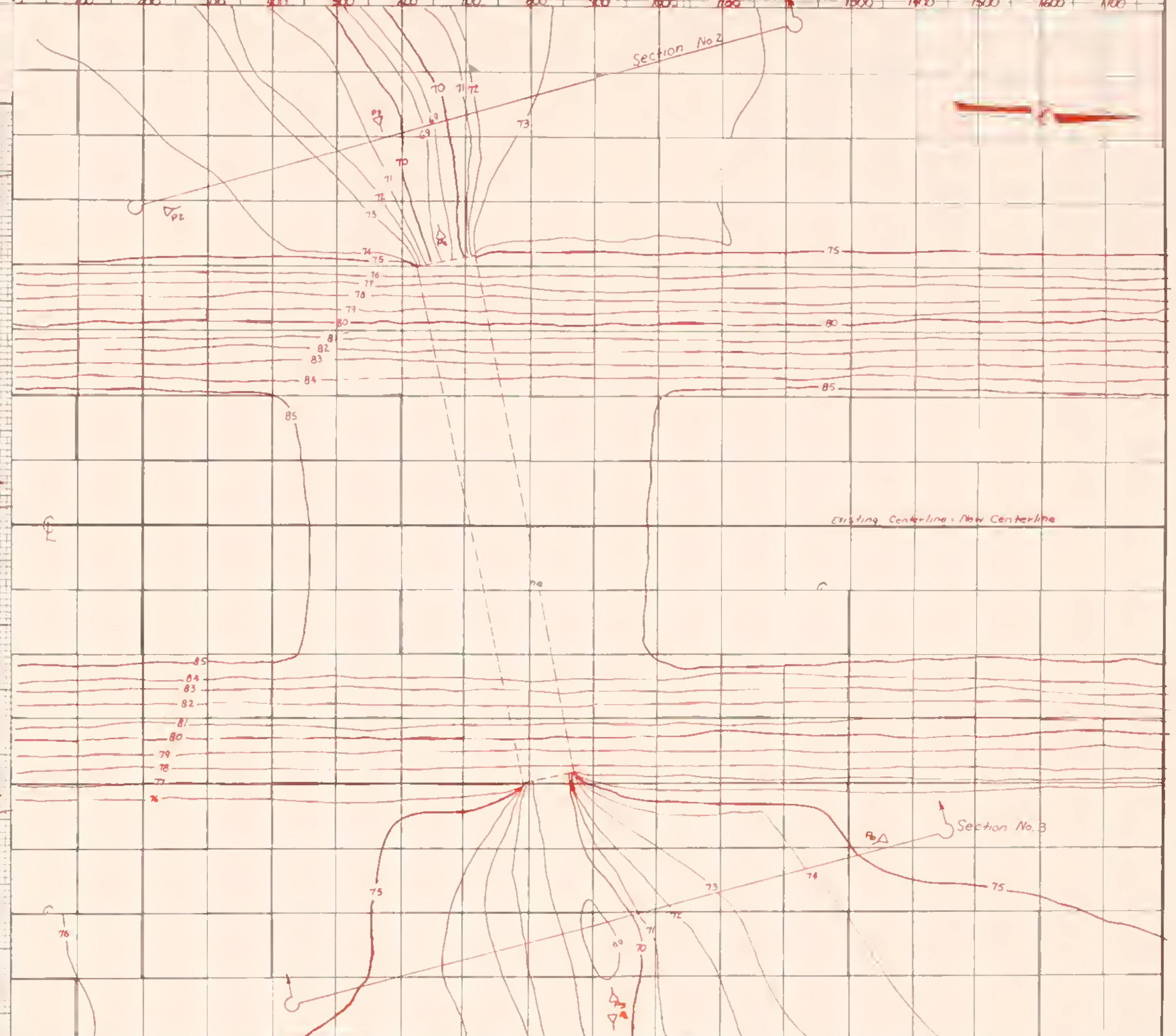
SECTION 6 CROSS SECTIONS

Scale Horizontal 1" = 10' ~~or as indicated~~ Vertical 1" = 5' ~~or as indicated~~

Instructions: Note, cross-sections should embody the following general characteristics, (1) Normal to channel (2) Section extremities to extend well above the maximum possible flood, (3) Vegetation described and accurately (±2) located, (4) Elevation differences of 6" or greater defined (5) Use scale of 1" = 10' vertical and horizontal unless there is an extensive flood plain. In this case, a smaller horizontal scale may be used so as to define the flood plain and low water channel. The low water portion should also be plotted again using a larger scale.
(A) Provide typical section downstream from all proposed structures (B) Provide cross section at approximate construction limits upstream and downstream from all proposed crossings (C) Provide section under existing bridges to include substructure details, spill-slopes, channel, and high water marks (D) Provide typical section of any irrigation ditches, etc. that will be affected by the construction (E) Indicate location of each section in Section 5 and 8 (F) [illegible] (G) When there is not enough room on this sheet, plot addition cross sections on a sheet of cross section paper and attach it to this sheet.



SECTION 8 PLAN



Instructions: (A) Use scale 1" = 10', ~~1" = 20', or 1" = 50'~~ depending on extent of field data (B) Indicate stationed centerline of survey (C) Draw contours with an interval as small as can be clearly shown (Contours are not necessary for irrigation) (D) Indicate elevation, location, and nature of damage that would result from flooding. If overtopping of finish grade only, check here ☐ (E) Stream meander and edge of water on date of survey (F) Indicate location of cross-sections shown in Section 6. (G) Indicate existing roads and structures (H) Indicate other features that may influence design.

SECTION 2.2
IRRIGATION

2.2 IRRIGATION SURVEYS

2.21 THE SURVEY

Anytime a proposed construction project will cross or in any way affect an irrigation ditch, an irrigation survey should be made. Form HYD-1 should be filled out completely with the exception of Section 1, Watershed Data. The watershed data does not apply to an irrigation crossing.

Section 2, Existing Structure, and Section 3, Erosion and Geology Data should be completed in the same manner as for a natural waterway.

Much of the information requested in Section 4 will require some research but it is extremely important and must be completely filled in.

Because the ditch company must always be contacted for approval of plans, the name of the ditch and the name and address of the owner should be provided. Many times a government agency such as the U.S. Bureau of Reclamation, U.S. Bureau of Indian Affairs, or the Montana Department of Conservation and Water Resources will have control and jurisdiction over an irrigation district. If this is the case, the name of the agency concerned should also be provided.

The hydraulic data requested in Section 4 such as capacity, slope, depth and ditch dimensions should be those provided by the ditch company and not the surveyed values. If the ditch also carries flood water, this should be indicated and an explanation attached.

The location sketch should contain all the information required for natural drainages plus a layout of the entire irrigation system within the scope of the sketch. All main canals, laterals, and field ditches and their direction of flow should be shown. All hydraulic structures such as pipes, flumes, turnouts, drops, checks, and headgates should be located. The invert elevations of these structures should be indicated.

The cross sections taken for irrigation should be typical sections that will represent a section of the ditch. Anytime any of the channel characteristics, such as shape, area, vegetation and channel materials change, then

another cross section should be taken. The location of each section and the reach of the ditch for which each section is typical should be indicated in Section 5 and 8. Vegetation and channel bottom material should be accurately described so the channel roughness can be determined. Photographs of each typical section should be submitted.

A profile of the invert and a profile of the water surface should be provided for each ditch. Slopes as flat as .0002 ft./ft. are not unusual for irrigation ditches so it may be necessary to extend the profiles a long ways upstream and measure elevations to hundredths of a foot in order to establish the slope. The invert elevations of structures such as turnouts, checks, etc. should be recorded. If a channel change will be required, a profile should be run along the approximate channel change line.

The Plan (Section 8) should be completed in the same manner as for natural watersheds. However, the contours need not be drawn for irrigation crossings unless the crossing is so complex that it cannot be easily represented by a couple of cross sections.

Where the irrigation systems are complex and are to be involved with a revamping or possibly relocation of the irrigation, the irrigation ditch and facilities should be traced out far enough so that an adequate design can be made.

2.22 EXAMPLES

FORM HYO Example No. 6 Complex Irrigation

MONTANA DEPT OF HIGHWAYS

Survey Data for Design of Waterways

Project Fairfield E&W No F-65(7)
Stream Name Greenfield Ditch Sta 187+45
County Teton
Surveyed By C Peil Date 2 30 72

FOR DRAINAGES OF ONE SQUARE MILE OR LARGER AND ALL IRRIGATION

GENERAL INSTRUCTIONS

1 Fill out all blanks carefully giving all information obtainable See Section 2 of the Hydraulics Manual for more detailed instructions, discussions, and examples
2 Make any comments or provide any additional information that you feel may be pertinent to the design of this crossing
3 Comments of local residents will aid in filling out much of this information The division lab may be of some help when filling out Section 3
4 The ditch rider, farmer, or ditch company should be contacted when filling out Section 4 Attach any right-of-way agreements if they have been made
5 Submit all survey notes with this sheet
6 Submit photographs of all channel and overbank areas, and all existing structures Be sure they are well labeled Indicate the location and orientation of all photographs with an arrow(▷) in Section 8

SECTION 1 WATERSHED DATA NA

Estimated Drainage Area ______ Acres or Sq Miles
Area not contributing to runoff ______
Comment on land use or cover ______

Floating Debris None ☐, Light ☐, Medium ☐, Heavy ☐
Other ☐, Quantity of Debris ______
Ice Light ☐, Moderate ☐, Severe ☐,
Unusual Characteristics ______

Elev of water on date of survey ______
Elev of low water ______, normally dry ☐
Elev of high water ______, date occured ______
Cause Backwater from ice ☐, Backwater from Construction ☐, Cloudburst ☐, Spring runoff ☐
Will ponding of water upstream cause damage to buildings or other property ______ If so what elev will water be allowed to reach ______
Should crossing be designed for fish passage ______

SECTION 2 EXISTING STRUCTURE

A Culvert Size ______, Type ______
Condition ______, Length ______
B Bridge Type Flat Slab Concrete
No of spans 1 Length of each span 26.0'
Clearance (Flowline to low beam) 4.5
Condition Fair (Some concrete is scaling)
Approx distance above or below site Same Site
Highwater mark elev ______
Historical adequacy Adequate
Comments ______

SECTION 3 EROSION AND GEOLOGY DATA

Do banks or bed show scour? No, is channel stable ☑, degrading ☐, agrading ☐, unknown ☐ Is riprap or bank protection necessary? No
Are the following material available locally
Riprap Yes, Type A or B, Filter Material No 1 Yes, No 2 Yes
Is water or soil alkaline No, acidic No, are sulphates present No
Comments ______

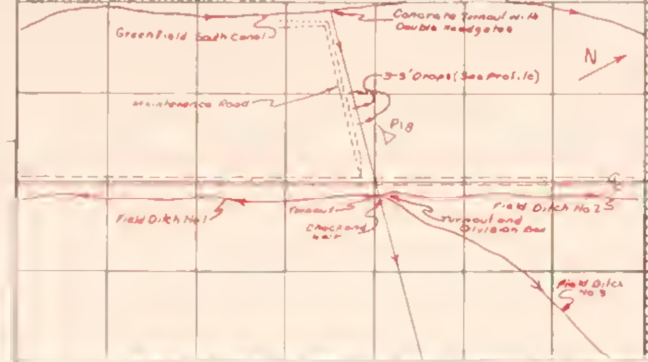
SECTION 4 IRRIGATION DATA

Name of ditch Greenfield Ditch
Owner Greenfield Irrigation Co.
Address of ditch company Fairfield Mont
Ditch capacity 60 cfs, Slope .0008, Water Depth 3.5, Bottom width 10.0, Side Slopes 2:1, Total Depth ______
Does ditch carry flood water also? No Flow line elevations of existing structure, inlet ______ outlet ______

COMMENTS Greenfield Irrigation Co said they felt a culvert was unacceptable for this crossing. They also said they require 1' minimum freeboard on all bridges crossing their canals.

SECTION 5 LOCATION SKETCH (Scale 1"=500')

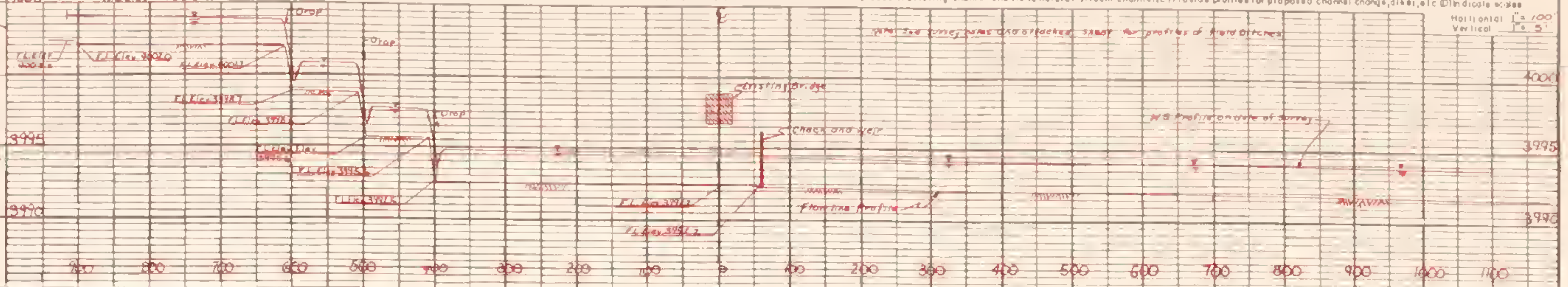
Instructions Show ℄ of survey, north arrow, general course of stream, existing structures, location of all channel cross sections shown in Section 6, and all general topography.



SECTION 7 PROFILE

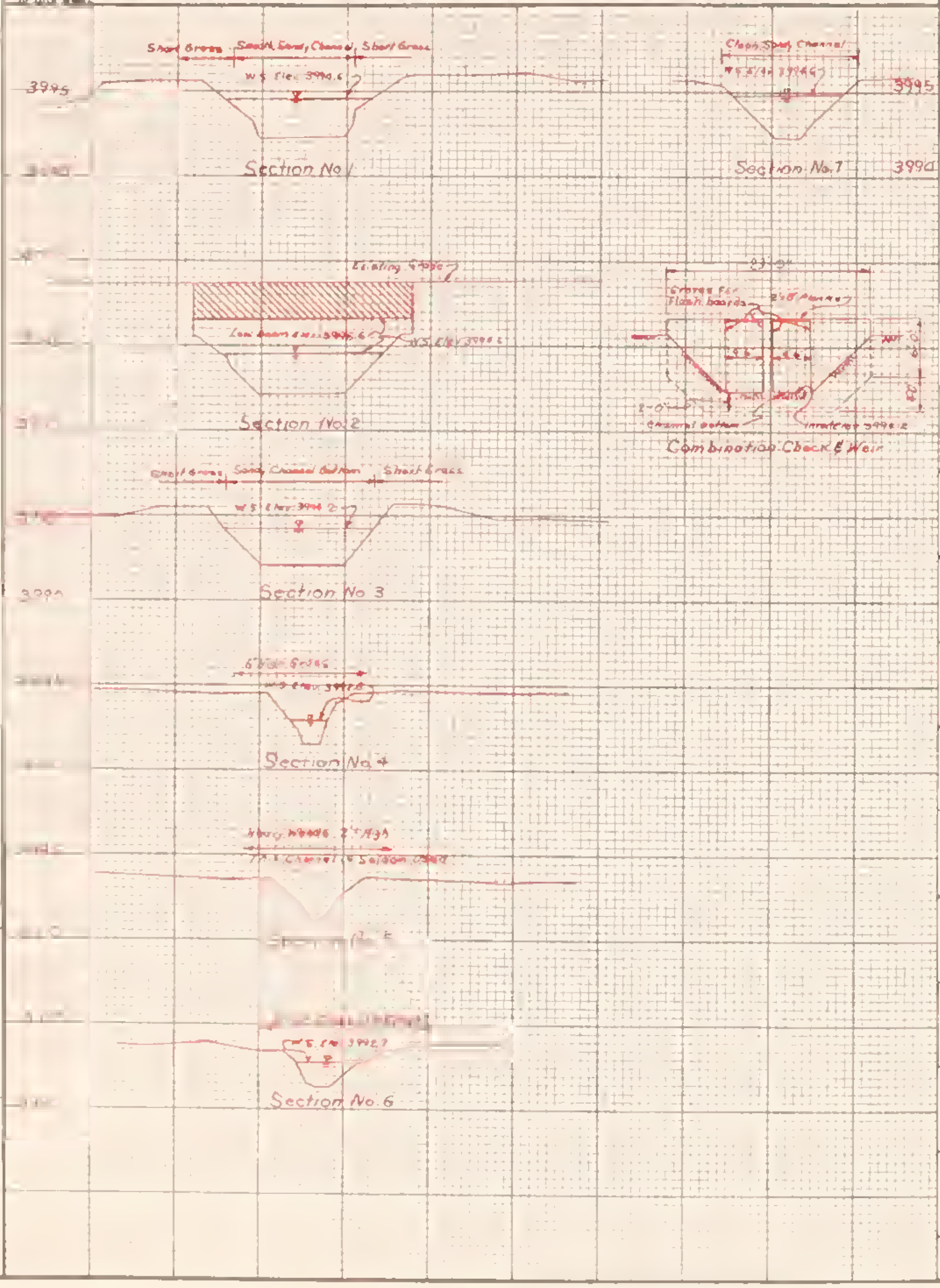
Instructions (A) Provide profiles of both the water surface and flowline of the existing channel for a minimum distance of 1500 ft up and downstream from the centerline Extend this profile when necessary to incorporate features natural or manmade features that will influence the proposed construction (B) Provide a profile along centerline of the proposed pipe when culvert will not be placed in existing channel and tie to natural stream channel (C) Provide profiles for proposed channel change, dikes, etc (D) Indicate scales

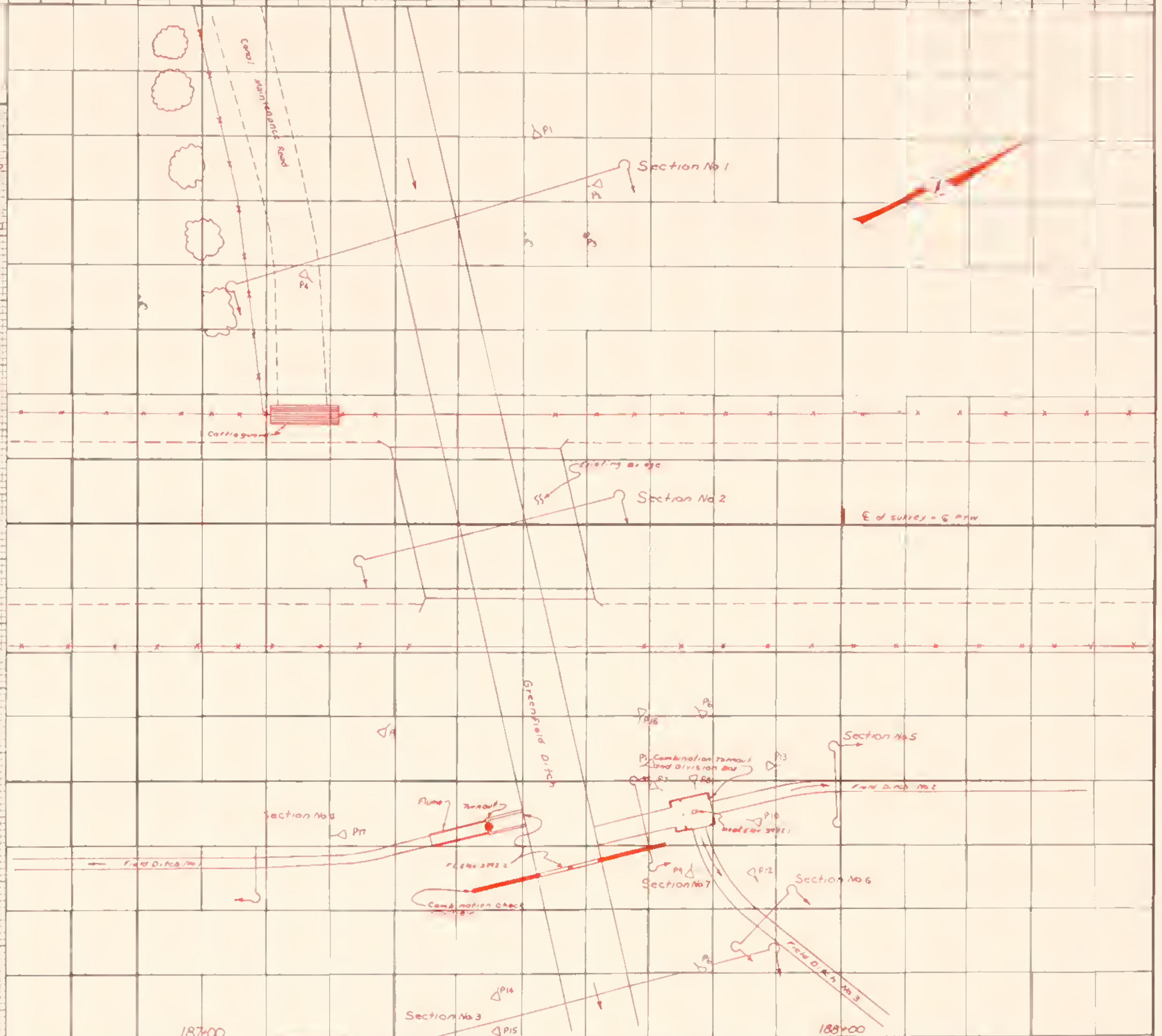
Horizontal 1" = 100'
Vertical 1" = 5'



SECTION 6 CROSS SECTIONS Scale Horizontal 1" = 10' ~~or as indicated~~ ☐
Vertical 1" = 5' ~~or as indicated~~ ☐

Instructions Note, cross-sections should embody the following general characteristics, (1) Normal to channel (2) Section extremities to extend well above the maximum possible flood, (3) Vegetation described and accurately located, (4) Elevation differences of 6" or greater defined (5) Use scale of 1"=10' vertical and horizontal unless there is an extensive flood plain In this case, a smaller horizontal scale may be used so as to define the flood plain and low water channel The low water portion should also be plotted again using a larger scale
(A) Provide typical section downstream from all proposed structures (B) Provide cross-section at approximate construction limits upstream and downstream from all proposed crossings (C) Provide section under existing bridges to include substructure details, spill slopes, channel, and high water marks (D) Provide typical section of any irrigation ditches, etc that will be affected by the construction (E) Indicate location of each section in Section 5 and 8 (F) ... to this sheet





SECTION 8 PLAN

Instructions (A) Use scale 1"=10', ~~1"=20', or 1"=50'~~ depending on extent of field data (B) Indicate stationed centerline of survey (C) Draw contours with an interval as small as can be clearly shown (Contours are not necessary for irrigation) (D) Indicate elevation, location, and nature of damage that would result from flooding If overtopping of finish grade only, check here ☐ (E) Stream meander and edge of water on date of survey (F) Indicate location of cross-sections shown in Section 6 (G) Indicate existing roads and structures (H) Indicate other features that may influence design

FORM HYD 1 Example No. 7 Simple Irrigation

MONTANA DEPT OF HIGHWAYS

Survey Data for Design of Waterways

Project White Sulphur Springs-East No F-8(17)
Stream Name Brown's Ditch Sta 39+50
County Meagher
Surveyed By R Hoffman Date 12-25-72

FOR DRAINAGES OF ONE SQUARE MILE OR LARGER AND ALL IRRIGATION

GENERAL INSTRUCTIONS

1 Fill out all blanks carefully giving all information obtainable See Section 2 of the Hydraulics Manual for more detailed instructions, discussions, and examples
2 Make any comments or provide any additional information that you feel may be pertinent to the design of this crossing
3 Comments of local residents will aid in filling out much of this information The division lab may be of some help when filling out Section 3
4 The ditch rider, farmer, or ditch company should be contacted when filling out Section 4 Attach any right-of-way agreements if they have been made
5 Submit all survey notes with this sheet
6 Submit photographs of all channel and overbank areas, and all existing structures Be sure they are well labeled Indicate the location and orientation of all photographs with an arrow(▷) in Section 8

SECTION 1 WATERSHED DATA

Estimated Drainage Area ______ Acres or Sq Miles
Area not contributing to runoff ______
Comment on land use or cover ______

Floating Debris None ☐, Light ☐, Medium ☐, Heavy ☐
Other ☐, Quantity of Debris ______
Ice Light ☐, Moderate ☐, Severe ☐,
Unusual Characteristics ______

Elev of water on date of survey ______
Elev of low water ______, normally dry ☐
Elev of high water ______, date occured ______
Cause Backwater from ice ☐, Backwater from Construction ☐, Cloudburst ☐, Spring runoff ☐
Will ponding of water upstream cause damage to buildings or other property ______ If so what elev will water be allowed to reach ______
Should crossing be designed for fish passage ______

SECTION 2 EXISTING STRUCTURE

A Culvert Size 24", Type CSP-Sq Ends
Condition Good Length 34'
B Bridge Type ______
No of spans ______, Length of each span ______
Clearance ______
Condition ______
C Approx distance above or below site 10' Downstream
Highwater mark Elev —
Historical adequacy Adequate

Comments See photos for Details of turnout and division box

SECTION 3 EROSION AND GEOLOGY DATA

Do banks or bed show scour? No, is channel stable ☑, degrading ☐, agrading ☐, unknown ☐ Is riprap or bank protection necessary? No
Are the following material available locally
Riprap Yes, Type B, Filter Material No 1 Yes, No 2 Yes
Is water or soil alkaline No, acidic No, are sulphates present No
Comments ______

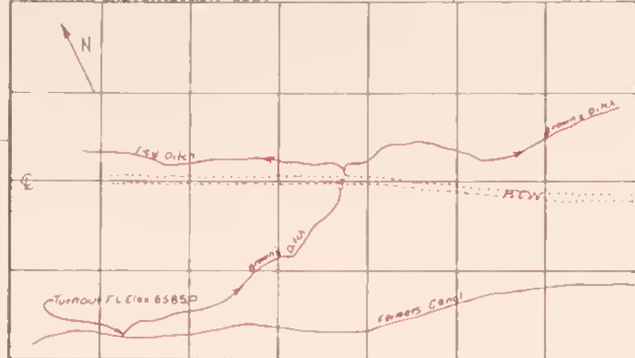
SECTION 4 IRRIGATION DATA

Name of ditch Brown's Ditch
Owner Tom Brown
Address of ditch company Route 2, White Sulphur Springs
Ditch capacity ______, Slope 0.5%, Water Depth 1.5', Bottom width 2.0', Side Slopes 1:1, Total Depth 2.5'
Does ditch carry flood water also? No Flow line elevations of existing structure, inlet 5581.3 outlet 5581.1

COMMENTS ______

SECTION 5 LOCATION SKETCH (Scale 1"=500')

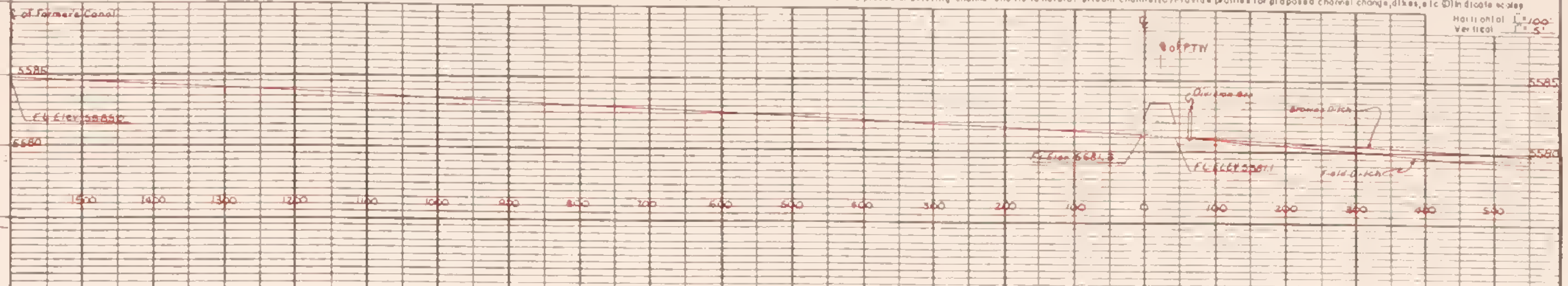
Instructions Show ℄ of survey, north arrow, general course of stream, existing structures, location of all channel cross sections shown in Section 6, and all general topography



SECTION 7 PROFILE

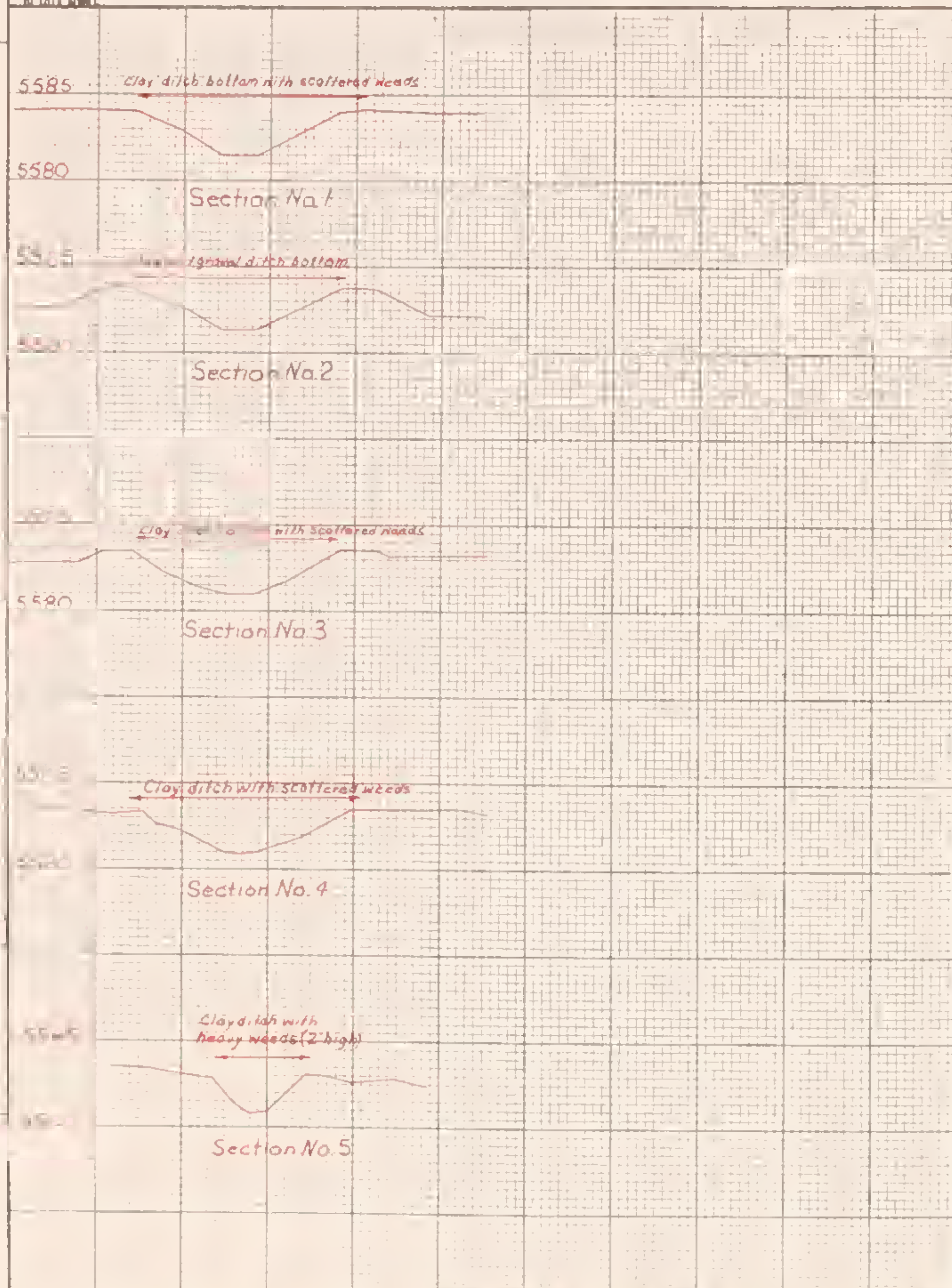
Instructions (A) Provide profiles of both the water surface and flowline of the existing channel for a minimum distance of 1500 ft up and downstream from the centerline Extend this profile when necessary to incorporate the natural or manmade features that will influence the proposed construction. (B) Provide a profile along centerline of the proposed pipe when culvert will not be placed in existing channel and lie to natural stream channel (C) Provide profiles for proposed channel change, dikes, etc (D) Indicate scales

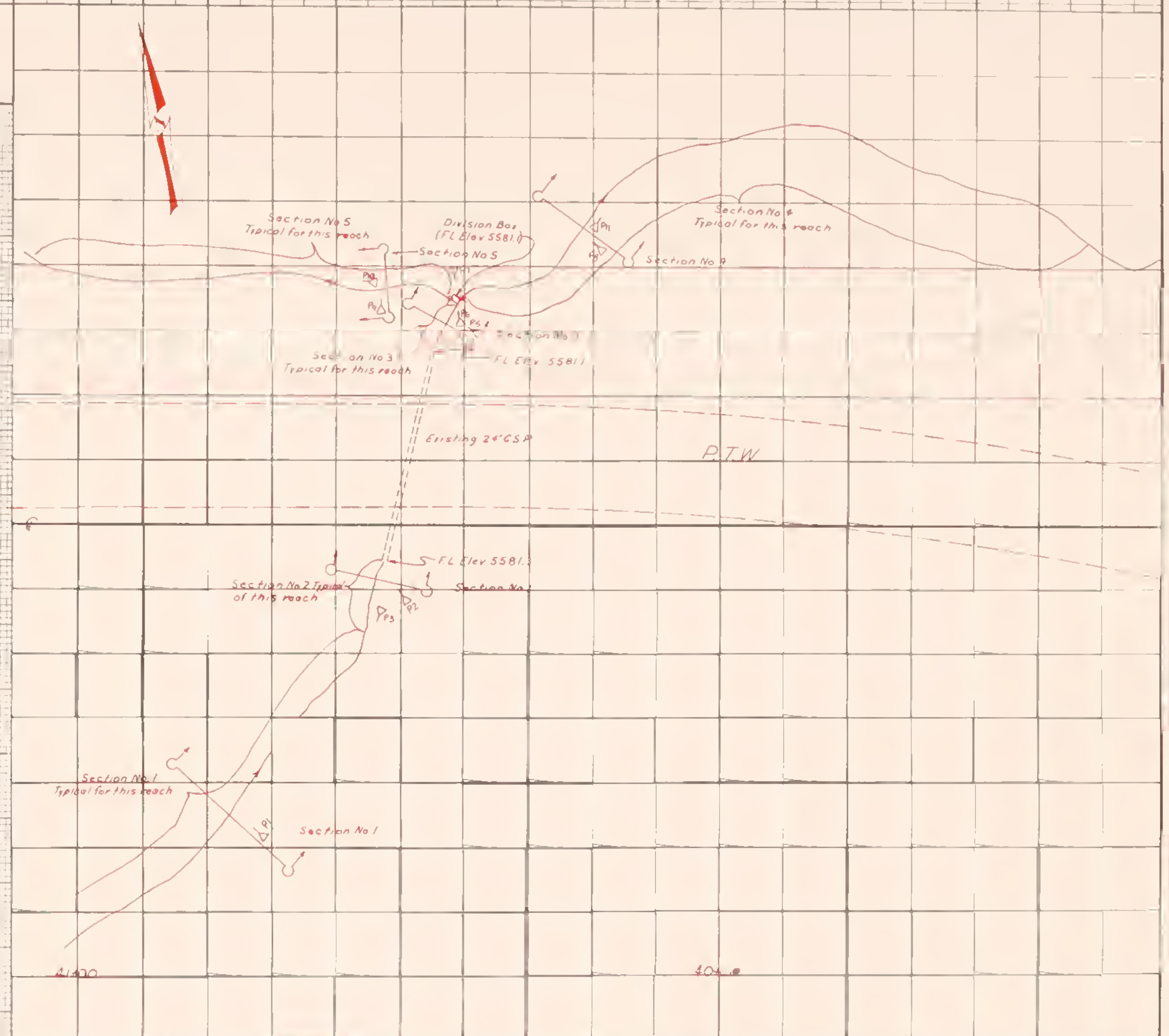
Horizontal 1"=100'
Vertical 1"=5'



SECTION 6 CROSS SECTIONS Scale Horizontal 1"=5' ~~or as indicated ☐~~
Vertical 1"=5' ~~or as indicated ☐~~

Instructions Note, cross sections should embody the following general characteristics, (1) Normal to channel, (2) Section extremities to extend well above the maximum possible flood, (3) Vegetation described and accurately located, (4) Elevation differences of 6" or greater defined (5) Use scale of 1"=10' vertical and horizontal unless there is an extensive flood plain in this case, a smaller horizontal scale may be used so as to define the flood plain and low water channel The low water portion should also be plotted again using a larger scale
(A) Provide typical section downstream from all proposed structures (B) Provide cross section of approximate construction limits upstream and downstream from all proposed crossings (C) Provide section under existing bridges to include substructure details, spill slopes, channel, and high water marks (D) Provide typical section of any irrigation ditches, etc that will be affected by the construction (E) Indicate location of each section in Section 5 and 8 (F) Attach photos of each section (G) When there is not enough room on this sheet plot addition cross-sections on a sheet of cross-section paper and attach it to this sheet





SECTION 8 PLAN

Instructions (A) Use scale 1"=10 ~~or 20, or 1"=50~~ depending on extent of field data (B) Indicate stationed centerline of survey (C) Draw contours with an interval as small as can be clearly shown [Contours are not neccessary for irrigation] (D) Indicate elevation, location, and nature of damage that would result from flooding if overtopping of finish grade only, check here ☐ (E) Stream meander and edge of water on date of survey (F) Indicate location of cross-sections shown in Section 6 (G) Indicate existing roads and structures (H) Indicate other features that may influence design

SECTION 2.3
WATER SUPPLY

2.3 WATER SUPPLY

The need for water for irrigation and domestic purposes is becoming greater as more landscaping projects and rest areas are built. The primary sources of water for these projects are wells and springs. Good information is needed to efficiently develop these sources.

2.31 WATER WELLS

The well information section of HYD-2 will provide the needed information about the well. A great deal of information is required to design the pumping and distribution systems and to efficiently develop the well. The required information is requested on Form HYD-2. It will be the responsibility of the Core Drill Section to see that the form is properly filled out and submitted to the Preconstruction Bureau.

The Well Information will provide the needed information about the well. The size and type of casing, size and location of perforations, and size and location of screens, if they are used, should be indicated on the form. Many times the casing and screens are pulled after test pumping and the contractor is required to redrill the well under the construction contract. If the casing and screens were pulled, this should be indicated on Form HYD-2. The elevation at the top of the well should be the ground elevation at the well and should serve as the datum for all measurements to the water level and bottom of the well.

The Water Information is extremely important and should be recorded accurately and completely. The value of a pumping test can be increased greatly with a little additional effort, time, and expense. Never be afraid to make too many measurements or observations. The depth of static water level should be measured before the test pumping starts and should be measured from the top of well datum elevation. The type and size of the test pump is used in analyzing the pumping test data.

The date on which the test pumping is done and the question about the amount of fluctuation in the water table are also important and deserve some time. If a pump test is run in May when the water table is high and the well is used in August when the water table has dropped considerably, problems could arise with the pumping system. Therefore, information about any fluctuation in the water table from year to year or season to season should be submitted. Local residents with nearby wells might be of some help in determining this information.

The pumping test should be conducted in accordance with good well testing procedures. The test should be run for a minimum of three (3) different production rates with the water pumped long enough at each rate to establish ultimate drawdown curves. The last rate should be near the maximum capacity of the well or 70 GPM. Some sprinkler systems require up to 70 GPM so the wells should be test pumped at these flows if possible. The time, pumping rate, and depth to water should be recorded continuously throughout the test. Water level recovery times and rates upon completion of pumping should also be recorded. The remarks might contain such information as appearance of water, temperature, etc. The length of the pump test will vary greatly depending on the aquifer. A sample of the water should be taken near the end of the test for chemical analysis.

A copy of the well log required by the Water Resources Division of the Department of Natural Resources and Conservation and a copy of the results of the water quality tests should be attached to Form HYD-2.

2.32 SPRINGS

Occasionally springs will be developed for water supply. When such a situation arises, the required information will be requested by the Hydraulics Unit on a case by case basis. However, certain information will always be required for the development of a spring. This information includes the elevation of the spring, an approximate flow rate, and the topography surrounding

the spring. A water sample for chemical analysis should also be submitted to the Department of Health and Environmental Sciences. Photographs of the area are also quite helpful and should be submitted.

FORM HYD. 2

MONTANA DEPARTMENT OF HIGHWAYS

WATER WELL INFORMATION

(To be completed and sent to the Hydraulics Unit)

Project Name ______________________________ No. __________

Well Location (tie to highway stationing) ______________________________

____

Well Information

Describe Casing ______________________________

____

Describe Perforations ______________________________

____

Was Casing Left in Place? __________

Describe Screens ______________________________

____

Were Screens Left in Place? ______________________________

Elevation at the Top of the Well (nearest tenth of a foot) __________

Depth of Well __________

Water Information

Depth to Static Water Level __________

Test Pump Used: Manufacter ______________________________, Model No. __________

__________, H.P. __________, Type of Pump ______________________________

Date of Test Pumping __________

Does Water Table Fluctuate with Seasons ______________________________

Test Pumping Log:

Date	Time	Pumping Rate	Depth to Water	Remarks

Reason for ending test pump (well should be test pumped until capacity is reached or 70 GPM are attained) ______________________________

____

Attach a copy of the well log required by the Montana Water Resources Board and a copy of the water quality tests.

Any comments or additional information that might be pertinent to the development of this well should be written on another sheet and attached.

SECTION 2.4
WASTE WATER DISPOSAL

2.4 WASTE WATER DISPOSAL

Whenever waste water and sewage are created such as in rest areas and weigh stations, some sort of disposal system much be constructed to dispose of them. The type of disposal system used in a particular situation depends primarily on two considerations: (1) the distance (in feet) to the water table from ground elevations and (2) the soil characteristics. A high water table eliminates the possible use of a drainfield because the Department of Health and Environmental Sciences requires the bottom of the drainfield to be at least 4.5 feet above the maximum ground water table. A highly impervious soil requires such a large drainfield that they become impractical.

The information required for the disposal system design includes a test for the ground water table elevation, percolation tests, and a contour map of the area.

At least one hole should be dug to determine the ground water table elevation. The hole should be excavated until the water table is reached or until it is seven feet deep and water is not encountered. It is felt that if the ground water table is over seven feet deep, it will not affect a drainfield. The ground water table elevation should be measured when the water table is at its highest point during the year. This is normally in the Spring.

Sometimes it is necessary to monitor the ground water elevation for an extended period of time. This is done by placing a shallow well in the ground and periodically recording the water elevation. The well should be placed by digging or boring a minimum of six inch diameter hole and placing a four inch perforated plastic pipe in it. The hole should then be backfilled with gravel and a cap placed on the top of the plastic pipe. It will be the responsibility of the Hydraulics Unit to request the well and give the approximate placement location. The approximate depth and the frequency with which the water elevation should be recorded will be provided with the request for the well.

Percolation tests determine the acceptability of the site and aid in the

design of the subsurface disposal system. The length of time required for making percolation tests will vary in different types of soil. The best method is to make tests holes which have been kept filled overnight with water. A minimum of four percolation test holes should be made in the drainfield area; more if there is a variation in the soil texture throughout the area. The following procedure is suggested for making percolation tests:

1. Dig or bore the hole 4 to 12 inches in diameter, sides vertical, to a depth of at least three feet. Holes can be bored with a four inch diameter posthole auger.
2. Roughen or scratch the glazed bottom and sides of the holes to provide a natural surface. Remove all loose materials from the hole. Place about two inches of coarse sand or fine gravel in the hole to prevent the bottom from scouring.
3. Fill the hole with clear water to a minimum depth of 12 inches over the gravel. By refilling, if necessary, or by supplying a surplus reservior of water (automatic siphon), keep water in the hole for at least four hours, and preferably overnight. In sandy soils containing no clay, the above saturation procedure is not necessary and the test can be made after the water from one filling has seeped away.
4. Percolation rate measurements should be made on the day following the saturation process, except in sandy soils.
5. If water remains in the test hole after overnight saturation, adjust the depth to six inches over the gravel. From a fixed reference point, measure the drop in water level over a 30 minute period.
6. If no water remains in the hole after overnight saturation, add clear water to a depth of about six inches over the gravel. From a fixed reference point, measure the height of the water surface at approximately 30 minute intervals over a four hour period, refilling the hole to a depth of six inches as necessary. The drop which occurs

during the final 30 minute period is used to calculate the percolation rate.

7. In sandy soils, or other soils in which the first six inches of water seeps away in less than 30 minutes, after the overnight saturation period, the time interval between measurements can be taken as 10 minutes and the test run over a period of one hour. The drop which occurs in the final ten minute period is used to calculate the percolation rate.

A contour map of the proposed drainfield area is necessary for the design of the drainfield. A contour interval of at least one foot is required.

The unit in charge of selecting the rest area site will request percolation tests for determining the adequacy of the site for a waste disposal system. It is the responsibility of the Hydraulics Unit to request any additional data, such as percolation tests or ground water elevations, for the final waste disposal system design. The Hydraulics Unit will supply a sketch of the rest area which shows the approximate location where the water table should be checked, the number and approximate location of the percolation tests, and the approximate area (including the comfort station) that should be contour mapped.

Any additional information that could be pertinent to the design of a waste disposal system should also be sent to the Hydraulics Unit.

SECTION 2.5
WATER SURFACE PROFILE

2.5 WATER SURFACE PROFILE DATA

Sometimes it is necessary to determine the elevation of the water surface for a projected flood over a long reach of a stream or irrigation canal instead of at just one point in the channel. When a stream runs parallel to the highway fill, it is necessary to determine the water surface profile to see how it could affect the fill and that the roadway grade is sufficiently above the water surface. When there are several bridges crossing a stream in one vicinity it is necessary to consider all of the bridges together to determine their affect on the stream. These are examples of when it is necessary to determine the water surface profile for a reach of a stream.

It will be the responsibility of the Hydraulics Unit to request the data necessary to calculate the water surface profile. The Hydraulics Unit will supply a map, aerial photograph, or plan sheet which will indicate the reach of the stream for which information is required. The following is a description of the necessary data.

2.51 CROSS SECTIONS

It is necessary to take cross sections that will accurately describe the entire reach. The Hydraulics Unit will indicate on the map, photograph, or plan sheet the locations where cross sections should be taken. In addition, the survey personnel should take additional cross sections when certain conditions exist.

Whenever there is a significant change in area of the channel, the change should be well represented with cross sections. If there is a change in channel shape, such as if the channel changes from a wide, shallow section to a narrow, deep section, the cross sections must represent this. Slope is also represented by the cross sections and additional sections should be taken at all visible changes in slope. A stream that runs from pools to riffles should have sections taken at the upstream and downstream end of each pool and riffle. The channel material and overbank vegetation are also represented by the cross sections, so

anytime there is a significant change in these parameters, additional sections are required. Also, additional points within a given cross section are required at changes in channel material and vegetations. Cross sections are required above and below the point where a tributary enters the subject stream.

Cross sections should always be taken at right angles to the flow. The sections need not be tied together if their location is accurately shown on a map, aerial photograph, or plan sheet for which a scale can be determined. Each section should be extended far enough to extend above the maximum possible flood.

2.52 EXISTING STRUCTURES

When a culvert is encountered in the stream, cross sections of the natural channel are required above and below the pipe. The size and type of the culvert and invert elevations at each end should be recorded. The finished grade elevation above the pipe is also necessary.

When there is an existing bridge, cross sections should be taken in the natural channel above and below the bridge and under the existing bridge. The number, width, and type of piers, the low chord elevation at the abutments, and the finished grade elevations are required.

A brief discussion of the historical adequacy of the existing structures should be included if known. Also, highwater elevations and dates of occurrence at existing structures should be included if available.

2.52 PHOTOGRAPHS

Photographs can be used to describe streambed material and overbank vegetation. Well labeled photographs should be taken of every cross section. Pictures should also be taken of the channel above and below each cross section. The photographs should be taken at a time when there is no ice on the stream and no snow to obscure streambed material and vegetation.

SECTION 2.6
URBAN STORM DRAINAGE

2.6 URBAN STORM DRAINAGE

The information required to design a storm sewer is extensive and variable. This makes it difficult to give a complete and accurate description of the needed information. The intent here is to give the survey personnel a general idea of what is needed and why it is needed and let them use their judgement in conducting the storm drainage survey.

2.61 CONTRIBUTING AREA

Determining the area that contributes to the storm sewer runoff is the most difficult part of the storm sewer survey. Most storm sewers pick up water that runs onto the highway from side streets. A detailed description of side drainages should be given so drainage areas and runoff coefficients can be determined. The description should include such information as drainage limits, direction of flow on each street, approximate street grades, street widths, type of surfacing, land use (residential, commercial, etc.), location at which it intercepts the highway, and location and size of any large paved areas such as parking lots. If there is an existing storm sewer in place in any of the contributing areas, the location of all inlets, manholes and the size of pipe should be given. Most of this information can most easily be given on a map of the area that is drawn to scale and is large enough to show all necessary details. Any other information that could be pertinent to the design of the storm sewer system should also be included.

2.62 OUTFALLS

It is always necessary to discharge the storm sewer into a natural drainage at some point or points along the system. It is the responsibility of the survey personnel to search out all possible outfall lines and provide a survey of each line. Some storm sewers will not have an obvious outfall line and a very detailed search will be required. If no outfall line can be found, the Hydraulics Unit should be so informed. The outfall survey should include a traverse tied to the centerline survey, all pertinent topography, and a profile.

2.63 SETTLING BASIN

Anytime a storm sewer is discharged into a perennial stream that contains fish life or is used extensively for drinking water, a settling basin is required near the stream. The purpose of the settling basin is to settle out silt, sand, and gravel. It can also be used, on occasion, as a seepage pit to allow some of the storm water to seep out naturally.

The settling pond should be located on the outfall line after all of the water has been collected. The shape of the basin can be varied to fit the area available. A minimum of one acre of land is required and it must be on or immediately adjacent to the outfall line. A contour map should be made of the prospective settling basin with a contour interval of one foot. This map should be submitted to the Hydraulics Unit with the other storm sewer survey data.

2.64 UTILITIES

All buried utilities that could affect the installation of the storm sewer must be accurately located. The size, depth and location of each utility must be recorded. The depth given should be referenced to some datum. The flow line elevations of all manholes and connections on gravity systems such as sanitary sewers and storm sewers should be given when possible. The utility companies and the city will have to be contacted to get most of this information. If for some reason they cannot provide the needed information, some field work may be necessary.

SECTION 2.7
EARTH FILL DAMS

2.7 SMALL EARTH FILL DAMS

It is sometimes possible to use a highway fill as a small dam and back up water either for flood routing purposes or for use as a stock pond. This situation will usually require a crossing with a small drainage area (ten square miles or less) and a high fill. In order to safely design such a crossing, some special information is required in addition to a completely filled out waterway crossing sheet (Form HYD-1). It will be the responsibility of the Hydraulics Unit to request the additional information when it is felt the fill could possibly be used in this manner.

A discussion of damage that could result if the fill washed out should be given. The location and description of all buildings, crops, ditches, etc. that are downstream from the highway and could be damaged should be submitted.

It is necessary to determine the storage capacity of the reservior that will build up behind the fill. In order to do this, a contour map of the area upstream is required. A contour interval of five feet is normally sufficient. The contours should go as high as the top of the fill.

The location and elevation of anything on the upstream side of the fill that could be flooded and damaged should be recorded. Some description of the land and vegetation that could be flooded should also be provided.

It will also be the responsibility of the Hydraulics Unit to request the Materials Bureau to supply a soils survey and their recommendations for construction of the fill.

SECTION 2.8
ROADSIDE EROSION

2.8 ROADSIDE EROSION

Erosion in roadside ditches, median ditches, on cut and fill slopes, etc., is a problem that should be handled during the original design. However, because of the lack of information and the tremendous amount of work involved in checking every situation on every project, erosion problems are often over looked during the original design. The best way to recognize potential erosion situations is by reviewing similar situations in the immediate vicinity.

It shall be the responsibility of the survey personnel to recognize, note, and comment on all potential erosion locations at the time the location survey is made. Note should be taken of any erosion in existing roadside ditches, on cut and fill slopes, on hill sides and in nearby gullies. If these locations show signs of erosion, then the potential for erosion of the newly exposed slopes of the new highway is great. If a particular erosion control method or material has worked well in the past in the vicinity, recommendations concerning that particular method or material should be made.

SECTION 3
HYDROLOGY

SECTION CONTENTS

CHARTS

FIGURES

TABLES

SECTION 3.1
MONTANA HYDROLOGY

3.1 GENERAL DESCRIPTION OF MONTANA HYDROLOGY

3.11 TOPOGRAPHY

The State of Montana is divided into the Northern and Middle Rocky Mountain and Great Plains physiographic provinces. About the eastern three-fourths is in the Great Plains; the western part is an area of mountains and intermontane valleys. Many peaks in the Rocky Mountains exceed 10,000 feet in altitude. The streams west of the Continental Divide in Montana have cut to lower altitudes than those east of the divide. The lowest point in Montana is about 1,800 feet above sea level where the Kootenai River enters Idaho. The plains area slopes generally eastward from about 4,000 feet near the mountains to 2,000 to 3,000 feet at the east edge of the State, but the slope is interrupted by basins and ranges of hills and mountains of structural origin.

3.12 DRAINAGE

The area east of the Continental Divide drains almost entirely into the main stem of the Missouri River or its prinicple tributary, the Yellowstone River; with a small area between Hudson Bay Divide and the Continental Divide being drained by the St. Mary River to Hudson Bay through the Saskatchewan River in Canada. The western part is drained by tributaries of the Columbia. The Kootenai River enters Montana from Canada and flows into Idaho. The Clark Fork receives the Flathead River from Canada and numberous tributaries from Montana and then flows into Idaho.

There are a few small closed basins near the Canadian border east of the Continental Divide and also a few in the area northwest of Billings.

3.13 CLIMATE

The climate of Montana is controlled by factors such as the location of the State on the continent, a barrier effect from high mountains in the western part of the State, altitude, latitude, and the general movement of air masses. West of the Continental Divide the climate is of the northern Pacific Coast type,

while east of the Divide it is of the Great Plains type.

Montana has relatively high temperatures during the summer and low temperatures in the winter. The average temperature for July is about 68 degrees ranging from an average of 65 degrees in the west to 72 degrees in the southeast. The average January temperature is about 19 degrees ranging from 10 degrees in the northeast to 22 degrees in the south central. There is a wide range in maximum and minimum temperatures. Temperatures exceeding 100 degrees have frequently been recorded in some localities. A low of -70 degrees was recorded at Rogers Pass on January 20, 1954.

The average annual frost penetration varies from 20 inches in the western mountains to 45 inches in the eastern part of the state.

Precipitation ranges widely in Montana and depends largely upon topographic influences. The mountain ranges and the areas adjacent to mountain ranges, in general, are the wettest, although there are a few exceptions where the "rain shadow" effect appears. The western part of the State is the wettest and the south-central part near the Wyoming boundary is the driest. A few valleys in the west, such as the Deer Lodge and Little Bitterroot, are relatively dry. Annual percipitation ranges from less than 10 inches near Helena to more than 100 inches at Grinnel Glacier in Glacier National Park.

Annual snowfall ranges from quite heavy (up to 300 inches) in some parts of the mountains in the western half of the State to about 20 inches in parts of northern Montana east of the Continental Divide. Most snow falls during the November - March period, but heavy snowstorms can occur as early as mid-September or as late as May 1 in the higher parts of the southwestern portion of the State. In eastern Montana early or late season snows are not common.

3.14 RUNOFF

The mean annual runoff ranges from more than 100 inches to less than

0.25 inch and averages about 3.5 inches for the State. Mountainous areas west and east of the Continental Divide have relatively high runoff. About half of the State has less than one inch of runoff.

Flood peaks in the western half of the State and in the major streams of the eastern half are generally caused by snowmelt and usually occur from March to June. In smaller drainages of the eastern part of the State, flood peaks are most often caused by rainfall either as general storms or as intense small-area thunderstorms and may occur from spring through fall. Some of the greatest floods of record have resulted from heavy rainfall on snow and frozen ground; such a situation caused the great floods of June, 1964. Other significant floods occurred in 1933, 1948, 1952, 1953, 1972, and 1975.

SECTION 3.2
MONTANA
GAGING PROGRAMS

3.2 STREAM GAGING PROGRAMS IN MONTANA

Stream gaging data is an important commodity when performing a hydrologic analysis. To be of maximum value, this data must be adequate to define the limits of a homologous region with respect to runoff characteristics both for small and large drainage areas. Once a region has been defined, the data is also used to predict runoff for ungaged streams within the region. There are three possible results inherent with designing a structure for a runoff with a certain recurrance interval, two of which are bad. First, the runoff can be estimated fairly accurately with the structure designed to carry the flow with little or no damage to nearby property or the roadway. Second, the runoff can be estimated too low with resulting damages to landowners and the roadway or the structure. Third, the runoff can be estimated too high with resulting expenditures for a structure that is overdesigned.

There are presently two gaging programs underway in Montana which are providing additional streamflow data each year. The objectives of these programs are to collect flood frequency information on a sufficient number of drainage areas for a sufficient number of years to adequately allow estimation of flood magnitude and frequency at any ungaged site with the reliability attainable when ten or more years of gaged record are available.

The first of these programs is funded and administered by the U.S. Geological Survey. The stations under this program are primarily recording gages and are placed on streams with a wide range of drainage areas. Some of these stations have over 60 years of record dating back to the 1890's.

The other gaging program is also administered by the Geological Survey but is financed primarily by the Montana Department of Highways with aid from other State and Federal agencies. This program consists primarily of crest-stage gages placed on drainages which are generally less than 500 square miles in area. Over one-half of these crest-gages are on streams with a drainage area

of less than 10 square miles and about one-fifth are on streams with drainage areas under 2 square miles. This program was established in 1955 with 45 stations. The program was expanded to 138 stations in 1959, and to 202 stations in 1963. About 200 stations were in operation from 1963 t0 1967, 185 were in operation from 1968 through part of 1970, and 182 through the remainder of 1970 and through 1972. The present program calls for continuation of 62 of the previously existing crest-stage gages on statewide basis until 30 years of record are obtained, continuation of all previously existing crest-stage gages that have less than 15 years of record until a minimum of 15 years are obtained, and installation of 100 additional crest-stage gages to obtain 15 years of record.

The Geological Survey periodically publishes all stream flow data in their Water-Supply Papers. These records are published on five and ten year intervals. The records from gages on drainages in the Hudson Bay Basin, The Pacific Slope Basin, and the Missouri River Basin are published in separate Water-Supply Papers. The Geological Survey also publishes annual surface water records for all gages in Montana in "Water Resources Data for Montana."

"Annual Peak Discharges From Small Drainage Areas in Montana", also published by the Geological Survey, contains records for gages in the Department of Highways sponsored program. These records are updated annually.

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SECTION 3.3
FLOOD PREDICTIONS ON
GAGED STREAMS

3.3 FLOOD PREDICTIONS ON GAGED STREAMS (STOCHASTIC METHODS)

The most reliable estimates of peak discharges for locations where runoff events are recorded, can be made by the use of stochastic methods. Stochastic methods are those that analyze the recorded events statistically to predict a flood peak with a desired return frequency. The dependability of the results of such an analysis is proportional to the number of recorded events.

Of several stochastic relationships which have been advanced, the Gumbel and Log-Pearson Type III methods give the best results. T. T. Williams in his "Drainage Correlation Research Project" examined both of these methods in detail and concluded that neither method gave the best results consistently. The results of both methods should be analyzed on an individual basis and those results that seem most reasonable should be used.

Both the Gumbel and Log-Pearson Type III are presented in detail in this section. In addition, computer program "PF Basic" is available which will perform the computations for both methods. "PF Basic" is described in Section 3.33.

The following terms and definitions are relative to both methods:

Recurrence Interval - Tp - The recurrence interval is the average interval in years between a flood of a specified magnitude and an equal or larger flood. If an event has a true recurrence interval of Tp yr., then the probability, P, that it will be equaled or exceeded in any one year is:

$$P = \frac{1}{T_p}$$

Mean and Standard Deviation - The mean is customairly used as the average or central value of a series of values in a hydrologic analysis. The mean, $\overline{X}$, is the arithmetic average of all events in a series and is given by the formula:

$$\overline{X} = \frac{\Sigma X}{N}$$

where

X is the magnitude of an individual event, and

N is the number of years of record.

The standard deviation if the customary way of describing the divergence or scatter of events about the mean. The standard deviation, S, is given by the formula:

$$S = \sqrt{\frac{\sum (X-\overline{X})^2}{N-1}}$$

The values of X and $\overline{X}$ in these equations may be either arithmetic or logarithmetic.

3.31 GUMBEL METHOD

Fisher and Tippet in their paper entitled, "Limiting Forms of the Frequency Distribution of the Largest or Smallest Member of a Sample", showed that if one selected the largest event from each of many large samples, the distribution of these extreme events was independent of the original distribution and conformed to a limiting function. In 1941 Gumbel suggested fitting the extreme value distribution to flood data, because the annual flood could be assumed to be the largest of a sample of 365 possible values each year. The resulting techniques are referred to as the extreme value or Gumbel distribution.

This distribution is given by

$$P = e^{-e^{-y}}$$

where e is the based of the naperian logarithms and y, the reduced variate, is a function of probability.

The flood magnitude for a given recurrence interval or probability can then be calculated from

$$X = \overline{X} + KS$$

where

X is the flood magnitude

$\overline{X}$ is the meand of all floods in the series

S is the standard deviation of the series

and K is dependent upon the recurrence interval and number of years of record and is found in Table 3.1.

TABLE 3.1

K VALUES FOR GUMBEL DISTRIBUTION

Number of Years of Records	Return Period, Years Probability Reduced Variate, y	2.33 0.43 0.579	5 0.20 1.500	10 0.10 2.250	25 0.04 3.199	50 0.02 3.902	100 0.01 4.600	200 0.005 5.296
10		0.088	1.058	1.85	2.85	3.59	4.32	5.06
12		0.076	1.013	1.78	2.74	3.46	4.17	4.87
14		0.068	0.981	1.72	2.66	3.36	4.05	4.74
16		0.061	0.954	1.68	2.60	3.28	3.96	4.63
18		0.056	0.934	1.65	2.55	3.22	3.89	4.55
20		0.052	0.919	1.62	2.52	3.18	3.84	4.49
25		0.044	0.888	1.58	2.44	3.09	3.73	4.37
30		0.038	0.866	1.54	2.39	3.03	3.65	4.28
35		0.035	0.850	1.52	2.36	2.98	3.60	4.21
40		0.031	0.838	1.50	2.33	2.94	3.55	4.16
45		0.028	0.828	1.48	2.30	2.91	3.52	4.12
50		0.026	0.820	1.47	2.28	2.89	3.49	4.08
55		0.025	0.813	1.46	2.27	2.87	3.47	4.06
60		0.023	0.807	1.45	2.25	2.85	3.45	4.04
70		0.020	0.797	1.43	2.23	2.82	3.41	4.00
80		0.019	0.790	1.42	2.21	2.80	3.39	3.97
100		0.016	0.779	1.40	2.19	2.77	3.35	3.93

3.32 LOG-PEARSON TYPE III

The basis for this method was advanced by Pearson in 1922 and proposed for use in hydrologic studies by H. A. Foster in 1924. Pearson proposed 12 different distributions, but only his Type III has received serious consideration. L. R. Beard in 1962 described the logarithmic transformations which produce the distribution now termed Log-Pearson Type III.

In using this distribution, the mean, standard deviation and coefficient of skewness are computed using the logarithms of recorded discharges instead of the recorded values themselves. The list of N annual flood magnitudes X_1, X_2, --- X_N is transformed to a list of corresponding logarithmic magnitudes Y_1, Y_2, --- Y_N. The mean of the logarithms, $\overline{Y}$, the standard deviation of the logarithms, S, and the coefficient of skewness, g. are given by the following formulas.

$$\overline{Y} = \frac{\Sigma Y}{N}$$

$$S = \sqrt{\frac{\Sigma Y^2}{N-1}}$$

$$g = \frac{N \Sigma Y^3}{(N-1)(N-2)S^3}$$

The logarithm of the discharge for the selected recurrence interval or probability is given by the formula

$$\log Q = \overline{Y} + KS$$

K is determined from Table 3.2 using the skew coefficient and the recurrence interval. The discharge Q is found by taking the antilog of log Q.

When evaluating a series of events with this method, special considerations must be made for years when no flow was recorded. Since the logarithms of numbers less than one are negative, all years with recorded flows less than 1 c.f.s. should be assumed to have a flow of 1 c.f.s.

TABLE 3.2

K VALUES FOR LOG-PEARSON TYPE III DISTRIBUTION

Skew Coefficient (g)	Recurrence Interval in Years 2	5	10	25	50	100
3.0	-0.396	0.420	1.180	2.278	3.152	4.051
2.9	-0.390	0.440	1.195	2.277	3.134	4.013
2.8	-0.384	0.460	1.210	2.275	3.114	3.973
2.7	-0.376	0.479	1.224	2.272	3.093	3.932
2.6	-0.368	0.499	1.238	2.267	3.071	3.889
2.5	-0.360	0.518	1.250	3.363	3.048	3.845
2.4	-0.351	0.537	1.262	2.256	3.023	3.800
2.3	-0.341	0.555	1.274	2.248	2.997	3.753
2.2	-0.330	0.574	1.284	2.240	2.970	3.705
2.1	-0.319	0.592	1.294	2.230	2.942	3.656
2.0	-0.307	0.609	1.302	2.219	2.912	3.605
1.9	-0.294	0.627	1.310	2.207	2.881	3.553
1.8	-0.282	0.643	1.318	2.193	2.848	3.499
1.7	-0.268	0.660	1.324	2.179	2.815	3.444
1.6	-0.254	0.675	1.329	2.163	2.780	3.388
1.5	-0.240	0.690	1.333	2.146	2.743	3.330
1.4	-0.225	0.705	1.337	2.128	2.706	3.271
1.3	-0.210	0.719	1.339	2.108	2.666	3.211
1.2	-0.195	0.732	1.340	2.087	2.626	3.149
1.1	-0.180	0.745	1.341	2.066	2.585	3.087
1.0	-0.164	0.758	1.340	2.043	2.542	3.022
.9	-0.148	0.769	1.339	2.018	2.498	2.957
.8	-0.132	0.780	1.336	1.993	2.453	2.891
.7	-0.116	0.790	1.333	1.967	2.407	2.824
.6	-0.099	0.800	1.328	1.939	2.359	2.755
.5	-0.083	0.808	1.323	1.910	2.311	2.686
.4	-0.066	0.816	1.317	1.880	2.261	2.615
.3	-0.050	0.824	1.309	1.849	2.211	2.544
.2	-0.033	0.830	1.301	1.818	2.159	2.472
.1	-0.017	0.836	1.292	1.785	2.107	2.400
0	0	0.842	1.282	1.751	2.054	2.326

Table 3.2 K Values (cont'd)

Skew Coefficient (g)	Recurrence Interval in Years 2	5	10	25	50	100
0	0	0.842	1.282	1.751	2.054	2.326
- .1	0.017	1.846	1.270	1.716	2.000	2.252
- .2	0.033	0.850	1.258	1.680	1.945	2.178
- .3	0.050	0.853	1.245	1.643	1.890	2.104
- .4	0.066	0.855	1.231	1.606	1.834	2.029
- .5	0.083	0.856	1.216	1.567	1.777	1.955
- .6	0.099	0.857	1.200	1.528	1.720	1.880
- .7	0.116	0.857	1.183	1.488	1.663	1.806
- .8	0.132	0.856	1.166	1.448	1.606	1.733
- .9	0.148	0.854	1.147	1.407	1.549	1.660
-1.0	0.164	0.852	1.128	1.366	1.492	1.588
-1.1	0.180	0.848	1.107	1.324	1.435	1.518
+1.2	0.195	0.844	1.086	1.282	1.379	1.449
-1.3	0.210	0.838	1.064	1.240	1.324	1.383
-1.4	0.225	0.832	1.041	1.198	1.270	1.318
-1.5	0.240	0.825	1.018	1.157	1.217	1.256
-1.6	0.254	0.817	0.994	1.116	1.166	1.197
-1.7	0.268	0.808	0.970	1.075	1.116	1.140
-1.8	0.282	0.799	0.945	1.035	1.069	1.087
-1.9	0.294	0.788	0.920	0.996	1.023	1.037
-2.0	0.307	0.777	0.895	0.959	0.980	0.990
-2.1	0.319	0.765	0.869	0.923	0.939	0.946
-2.2	0.330	0.752	0.844	0.888	0.900	0.905
-2.3	0.341	0.739	0.819	0.855	0.864	0.867
-2.4	0.351	0.725	0.795	0.823	0.830	0.832
-2.5	0.360	0.711	0.771	0.793	0.798	0.799
-2.6	0.368	0.696	0.747	0.764	0.768	0.769
-2.7	0.376	0.681	0.724	0.738	0.740	0.740
-2.8	0.384	0.666	0.702	0.712	0.714	0.714
-2.9	0.390	0.651	0.681	0.683	0.689	0.690
-3.0	0.396	0.636	0.660	0.666	0.666	0.667

3.33 COMPUTER PROGRAM

The following program will analyze recorded flood data and print the 100, 50, and 25 year floods by the Log-Pearson Type III method and the 100, 50, 25, 10, and 2.33 (mean annual) year floods by the Gumbel Method.

Name: PF Language: Basic Input Format: Data (1420)

Purpose: Computes flood magnitudes by the Log-Pearson and Gumbel Methods.

Required Input Data: The flood records are input with data statements starting with statement No. 1121. These records need not be put in any kind of order. Enter flows of 0 c.f.s. as 0. The computer will then ask for the number of years of record.

Abstract: This program computes flood magnitudes from recorded peak discharges using both the Gumbel and Log-Pearson Type III Methods. All flows of less than 1 c.f.s. are changed to 1 c.f.s. for the Log-Pearson Type III Method. The computational procedures are the same as those presented in Sections 3.31 and 3.32.

Limitations: The maximum number of years of record the program will handle is 65.

EXAMPLE RUN

```
      edit pf basic
EDIT
        GRASSHOPPER CREEK NEAR DILLON   A= 348 SQ MI
EDIT
      1121 data 516,543,283,120,557,197,355,327,172,85,322,160
EDIT  1122 data 640,719,324,252,559,257,719,328,1870,433,579,539
EDIT  1123 data 252,450,465,539,634,180,730,435,1140,400,465,585
EDIT  run

THE NUMBER OF YEARS IS
  ?   36

FREQUENCY                 GUMBEL METHOD          LOG PEARSON METHOD

100 YEAR                   1629.4 CFS              1490.9 CFS
 50 YEAR                   1431.0 CFS              1298.8 CFS
 25 YEAR                   1231.2 CFS              1109.1 CFS
 10 YEAR                    961.8 CFS
MEAN ANNUAL (2.33 YR)       486.8 CFS

EDIT
```

ATTEN.

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SECTION 3.4
FLOOD PREDICTIONS ON
UNGAGED STREAMS

MONTANA DEPARTMENT OF HIGHWAYS
Helena, Montana 59620

MEMORANDUM

TO: Holders of Montana Department of Highways Hydraulic Manual

FROM: Stephen C. Kologi, P.E., Chief, Preconstruction Bureau

RE: Hydraulics Manual Update

DATE: November 4, 1981

Under a cooperative agreement, the U.S. Geological Survey has completed a report providing revised techniques for estimating magnitude and frequency of floods in Montana. We are hereby providing you with a copy of this report (Open-File Report 81-917) which is to be incorporated into the Hydraulics Manual provided you about six years ago.

We are unable to completely update the Hydraulics Manual at this time or provide copies of all the materials referenced below; however, this material is to be incorporated into the manual as follows:

a. Note in Section 3.3 that Log-Pearson Type III is used following the procedures outlined in the United States Water Resources Council's Bulletin #17A, "Guidelines for Determining Flood Flow Frequency." By this reference Bulletin #17A shall be incorporated into the Hydraulic Manual.

b. Note in Section 3.4 that references to the Dodge Method are to be replaced with the methods of Open-File Report 81-917.

c. Users of the Hydraulic Manual shall become familiar with the limitations of the regression equations presented in the Open-File Report and as discussed on page 16 of the report.

d. As in the past, the Hydraulics Manual does not attempt to show which flood prediction method is most appropriate for any given area or stream site but merely presents the methods commonly used. Users must exercise sound hydrologic judgment when evaluating each individual site.

e. We hope to be able to provide an update to the manual in the near future which will provide guidance on the requirements of FHPM 6-7-3-2. Until that time, FHPM 6-7-3-2 is hereby incorporated into the manual by reference.

f. After making the above notations, this memo shall be filed under Section 1 (Policy and Procedures).

In the past we have received numerous requests for copies of our Hydraulics Manual and previous Open-File Reports and we anticipate similar request for this report. If you feel that this Open-File Report will not be used by you or your staff, we request that you return it to the Hydraulics Unit.

Thank you for your cooperation.

34:SCK:CSP:cg:6C

Stephen C. Kologi

Attachment

DISTRIBUTION w/Attachment

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3.4 FLOOD PREDICTIONS ON UNGAGED STREAMS AND DRAINAGES

Introduction

When a flood prediction is required at a point on a stream where there is no gage, the lack of recorded data precludes the use of stochastic methods. This requires that either a parametric or a combination of parametric and stochastic methods be used. Parametic hydrology is the development of relationships amoung physical parameters affecting runoff and the use of these relationships to generate or synthesize hydrologic events.

One parametric method will be described in this section. This is the method presented by Dr. E. R. Dodge in his report entitled "Application Hydrologic and Hydraulic Research to Culvert Selection in Montana". Dodge analyzed the recorded peak discharge data for 230 watersheds throughout Montana, identified the significant parameters, and then developed prediction equations based upon those parameters. The Dodge Method is presented in Section 3.41.

The other flood prediction method presented in this section is based upon a combination of stochastic and parametric methods. It is called the Regional frequency Analysis method and is described in detail in Section 3.42.

Some other parametric flood prediction methods are discussed but not presented in Section 3.43.

3.41 FLOOD FREQUENCY CURVES DEVELOPED BY DR. E. R. DODGE

The flood prediction methods and charts presented here were developed by Dr. E. R. Dodge and presented in his "Application Hydrologic and Hydraulic Research to Culvert Selection in Montana" in 1971. Dr. Dodge used a linear regression analysis to divide the State into a contiguous flood regions and develop flood prediction equations for each region. The boundaries for the flood regions are shown in Figure 3.1.

All prediction equations were developed in the form

$$Q = b_o X1^{b1} X_2^{b2} \ldots . X_n^{bn}$$

where Q_1 = peak flow

b_o = regression constant

$b_1 b_2 \ldots\ldots b_n$ = exponents developed from regression

$X_1, X_2, \ldots\ldots X_n$ = independent variables

The regression analysis based on this equation produced five different prediction equations for each of eight regions, and ten different equations for Region V since the exponents on the independent variables were different for each recurrence interval. This resulted in a total of 50 different equations which are referred to as the Individual Exponent Equations and are listed in Table 3.3. This many equations were considered excessive, particularly because of the desire to prepare graphical solutions. To reduce the number of equations, a set of equations with "average" exponents were developed with only the regression constant varying with the recurrence interval of the flood. With these equations, referred to as the Average Exponent Equations, the flood prediction charts were drawn up. The average exponent equations are listed at the top of the appropriate charts. The individual exponents equations probably give somewhat more reliable predictions than the average exponent equations and should be used whenever possible.

Dr. Dodge analyzed 16 watershed parameters to identify which parameters significantly affected flood prediction in each region. A total of six

parameters were found significant, although not more than three are used in any given flood region. They are:

1. A = Drainage area, sq mi
2. F = Percent Forest Cover, %
3. %> 6000 = Percent area greater than 6000 ft., %
4. PS = SCS Mean Annual Precipitation, inch
5. I = Precipitation Intensity (2 year-24 hour), inch/24-hr
6. S = Soil Storage Index, inch

These parameters may be estimated for any given water shed by the following methods:

Drainage Area (A) The drainage area may be determined from any suitable topographic map on which it is possible to identify the boundaries of the watershed. When aerial photographs are available, they also can provide a way to determine drainage area.

Percent Area Above 6000 Feet. (%>6000) The percentage of the drainage area above 6000 feet may be determined from any contour map by laying a rectangular grid over the map, counting the number of grid intersections for all parts of the drainage area above 6000 feet, and then dividing this count by the total number of grid intersections which are required to cover the area.

Percent Forest Cover (F) The grid method used to find %>6000 can also be used to estimate F, the percentage of the drainage area covered by forest on a map which designates forest areas. The 1:250,000 Army Map Service maps, and USGS Quadrangle sheets indicate forested regions in green color. For small drainage areas recent aerial photo mosaics may provide better data than the above maps.

Mean Annual Precipitation (PS) The mean annual precipitation in inches can be determined from the isohyetal map of Figure 3.2. A weighted average should be used for drainage areas crossing several isohyets.

Precipitation Intensity (2-year 24-hour) (I) The precipitation intensity refers to the 2-year 24-hour duration rainfall amount which is to be expected for the design watershed. The value is referred to as precipitation-intensity rather than amount since for the specified 24-hour duration, it does measure an average intensity. These values may be obtained from the 1969 ESSA Weather Bureau map of Montana shown in Figure 3.3.

Soil Index (S) The soil index is a concept developed by the U.S. Soil Conservation Service. It represents values of potential maximum infiltration of rainfall in inches during an annual flood under average soil moisture conditions. Because the determination of this factor is quite complicated and because it will also be used in Section 3.6, the method for determining the soil index will be presented in Appendix A.

In many flood regions there may be considerable variation in flood potential in different water sheds, even for drainage areas with essentially the same prediction equation characteristics. This should not be surprising since it was also true of the data from which the prediction equations were derived. For this reason it will be helpful if the designer indicates whether the drainage area is considered typical of the Flood Region in which it is located or whether it is expected to produce higher or lower flood magnitudes than are typical. This indication requires considerable insight into the hydrologic phenomena producing floods, and should only be made by experienced competent engineers. Another consideration which should not be overlooked is that watershed conditions in the predictable future may be of more interest than conditions in the past or even at present.

Figure 3.1 shows the boundaries of the nine Flood Regions. These regions are designated I-IX and each is given a descriptive name indicating its location in Montana. Some drainage areas will be located near the border of a Flood Region. Although the prediction equations are different in each region, it is

unreasonable to expect that flood magnitude will change abruptly from one Flood Region to another. For such areas therefore, the designer should indicate which Flood Region best typifies the drainage area in question or how to weight flood estimates from each region to arrive at a reasonable estimate for the drainage area. The following discussion, which is concerned with illustrating various aspects of the flood prediction procedure, includes an example which illustrates the problem of making weighted flood estimates.

The procedure for determining design flood values from both the flood prediction charts and the prediction equations is illustrated by the following examples:

Example 1

Assume the design watershed is located near Lewistown, Montana in Flood Region II and has the following characteristics.

Drainage Area A = 10 sq mi

$\% > 6000 = 21\%$

2-year 24-hour intensity I = 1.6 inch/24 hour (see 1969 ESSA map figure 3.3.

Estimate the 2-year and 50-year flood for this watershed using both the flood prediction chart and the individual exponent equations for Region II.

From the Region II Flood prediction chart, Chart 3.3,

$Q_2 = 53.0$ cfs

Since in Region II

$Q_{50} = (6.18)\ (Q_2)$

$Q_{50} = (6.18)\ (53.0) = 328$ cfs

The individual exponent equations for Region II (see Table 3.3) are:

$Q_2 = 5.48\ A^{.724}\ \% > 6000^{-.162}\ I^{2.295}$

$$Q_{50} = 83.5\ A^{.695}\ \%> 6000^{-.472}\ I^{2.201}$$

Substituting the independent variable values into the above equations gives the following results:

$$Q_2 = 5.48(10)^{.724}\ (21)^{-.162}\ (1.6)^{2.29}$$

$$Q_2 = (5.48)(5.30)(1/1.64)(2.94) = 52.0 \text{ cfs}$$

and

$$Q_{50} = 83.5(10)^{.695}\ (21)^{-.427}\ (1.6)^{2.201}$$

$$Q_{50} = (83.5)(4.95)(1/3.66)(2.83) = 319 \text{ cfs}$$

Example 2

As indicated in Table 3.2, alternate equations are to be used in Regions III, V, and VIII depending on the magnitude of the F value for the design watershed. To illustrate consider a design watershed which is located in Region VIII. First estimate Q_{50} assuming the following independent variable values:

Drainage Area A = 25 sq mi

% Forest F = 80%

Mean Annual Precipitation PS = 31 in.

From the Region VIII Flood Predication Chart for F > 16%

$$Q_2 = 140 \text{ cfs}$$

and

$$Q_{50} = (2.56)(140) = 358 \text{ cfs}$$

Likewise if the individual exponent equation is used:

$$Q_{50} = (243)(25)^{.940}(31)^{1.266}(80)^{-1.591}$$

$$Q_{50} = (243)(20.4)(77.6)(1/1010) = 382 \text{ cfs}$$

However, if the watershed had an F value less than 16%, say 10%, it

becomes necessary to use the alternate prediction equations which do not include F as an independent variable.

From Table 3.2, the individual exponent equation is:

$$Q_{50} = (2.55)(A)^{.859}(PS)^{.646}$$

$$Q_{50} = 2.55(25)^{.859}(31)^{.646} = 372 \text{ cfs}$$

As previously indicated when working with design watersheds in Regions III, V, and VIII, the proper set of flood prediction equations to be used will be determined by the magnitude of the F value for the watershed. If the value of F is below 19% and 16% for Regions III and VIII, respectively, then the set of alternate equations should be used. Likewise, if F exceeds 9% in Region V it is necessary to use the alternate equations. A flood prediction chart has been prepared for the Region V alternate equations, however, the alternate equations for Regions III and VIII are solved manually as shown in this example since Charts for them were not prepared.

<u>Example 3</u>

In Table 3.3, it is seen that for Regions I and III the number of independent variables is not the same for all five recurrence interval equations. For example in Region III the 2 and 5 year equations contain the variables A, F and PS while the 10, 25, and 50 year equations contain only the A and F. Similarly the 2, 5, 10, and 25 year Region I equations contain A and PS while the 50 year equations use only A. The flood prediction procedure for these two regions is now illustrated by finding the 2, 10, and 50 year flood peaks for a watershed in Region III using the following data:

Drainage Area A = 110 sq mi

% Forest F = 51%

Mean Annual Precipitation PS = 28 in.

From the Region III Flood Prediction Chart for 2 and 5 year floods

Q_2 = 310 cfs

From the Region III Flood Prediction Chart for 10, 25, and 50 year floods:

Q_{10} = 480 cfs

and since $Q_{50} = (1.47)Q_{10}$

$Q_{50} = (1.47)\ (480) = 705$ cfs

Similarly, by use of the individual exponent prediction equations:

$$Q_2 = (.00172)A^{.970}\ F^{.758}\ PS^{1.39} = (.00172)(110)^{.970}(51)^{.758}(28)^{1.39}$$

$$=(.00172)(95.6)(19.5)(105) = 340 \text{ cfs}$$

$$Q_{10} = (.0793)A^{.911}F^{1.31} = (.0793)(110)^{.911}(51)^{1.131}$$

$$= (.0793)(72.6)(87.1) = 502 \text{ cfs}$$

$$Q_{50} = (.230)A^{.855}F^{1.023} = (2.30)(110)^{.855}(51)^{1.023}$$

$$= (.230)(56.1)(56.2) = 733 \text{ cfs}$$

Recall from Example 2 that Region III also has a set of alternate equations for use when F is less than 19%. However the same variables, namely A and PS, appear in all five of these alternate equations. Hence one is not concerned with using different variable combinations for different recurrence interval floods (as illustrated in this example) when using the Region III alternate equations.

Example 4

Consider now the problems associated with making flood predictions for a watershed located near the boundaries of two or more flood regions. Assume the watershed in question is located in Flood Region V but very close to the boundary between Region V and Region II.

Compute the design flood (Q_{50}) using the flood prediction charts for both Region V and II. The following watershed data apply:

Drainage Area A = 30 sq mi

% Forest F = 8%

% > 6000 = 19%

2 year-24 hour intensity I = 1.8 inch/24 hour

From the Region II Flood Prediction Chart, Chart 3.3,

$$Q_2 = 160 \text{ cfs}$$
$$Q_{50} = (6.18)(Q_2) = (6.18)(160) = 990 \text{ cfs}$$

From the Region V Flood Prediction Charts, Chart 3.8,

$$Q_2 = 55 \text{ cfs}$$
$$Q_{50} = (6.65)(55) = 365 \text{ cfs}$$

It is obvious that the above estimates of Q_2 and Q_{50} differ greatly in magnitude. Because of this a detailed analysis of the design watershed is needed to determine if either of these Q_{50} values is a preferred estimate best or how the two values should be weighted to give the most reasonable result. However, assuming that such detailed information is not available, the designer could arrive at a compromise between the two Q_{50} values by simply averaging them.

Thus

$$Q_{50} = \frac{990 + 365}{2} = \frac{1455}{2} = 727 \text{ cfs} \quad \text{(simple average)}$$

To illustrate a more refined procedure, assume that the field engineer has indicated that, according to his judgement, about 70% of the watershed is typical of characteristics common to Region V and about 30% is representative of conditions found in Region II. This type of information can be used to make a weighted prediction of the design flood.

The weighted prediction would be,

$$Q_{50} = (.3)(990) + .70(365)$$

$$= 297 + 256 = 553 \text{ cfs}$$

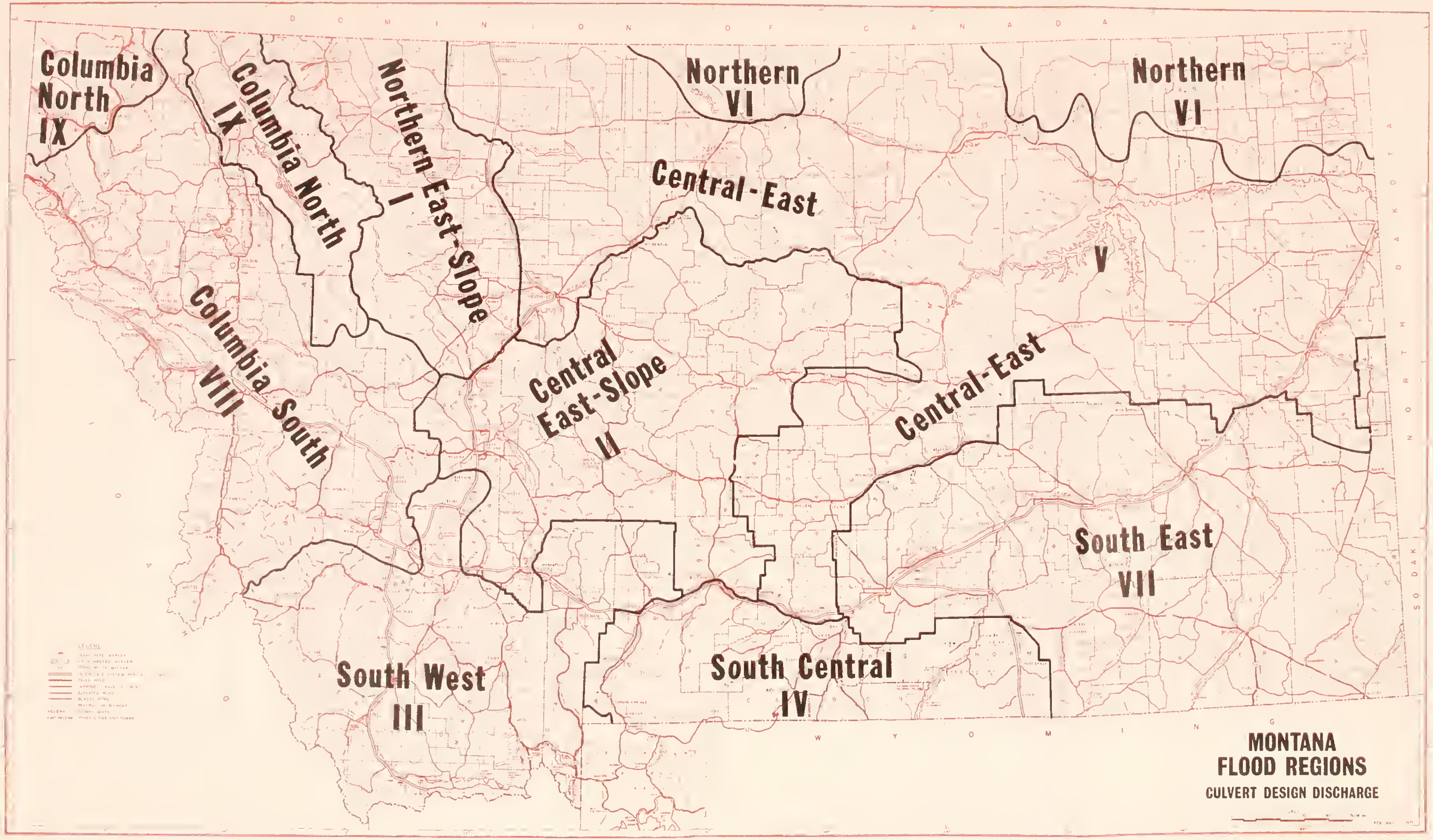

D O M I N I O N O F C A N A D A
Columbia North IX
Columbia North IX
Northern East-Slope I
Northern VI
Northern VI
Central-East
V
Columbia South VIII
Central East-Slope II
Central-East
South East VII
South West III
South Central IV
W Y O M I N G
MONTANA
FLOOD REGIONS
CULVERT DESIGN DISCHARGE

Fig. 3.1

STATE OF MONTANA
AVERAGE ANNUAL PRECIPITATION
IN INCHES

U.S. Soil Conservation Service 1953-67 Base Period

Variable PS

Fig. 3.2

MONTANA HIGHWAY DEPARTMENT CHART 3.1

CULVERT DESIGN DISCHARGE

2-YR. FREQUENCY REGION I NORTH EAST-SLOPE

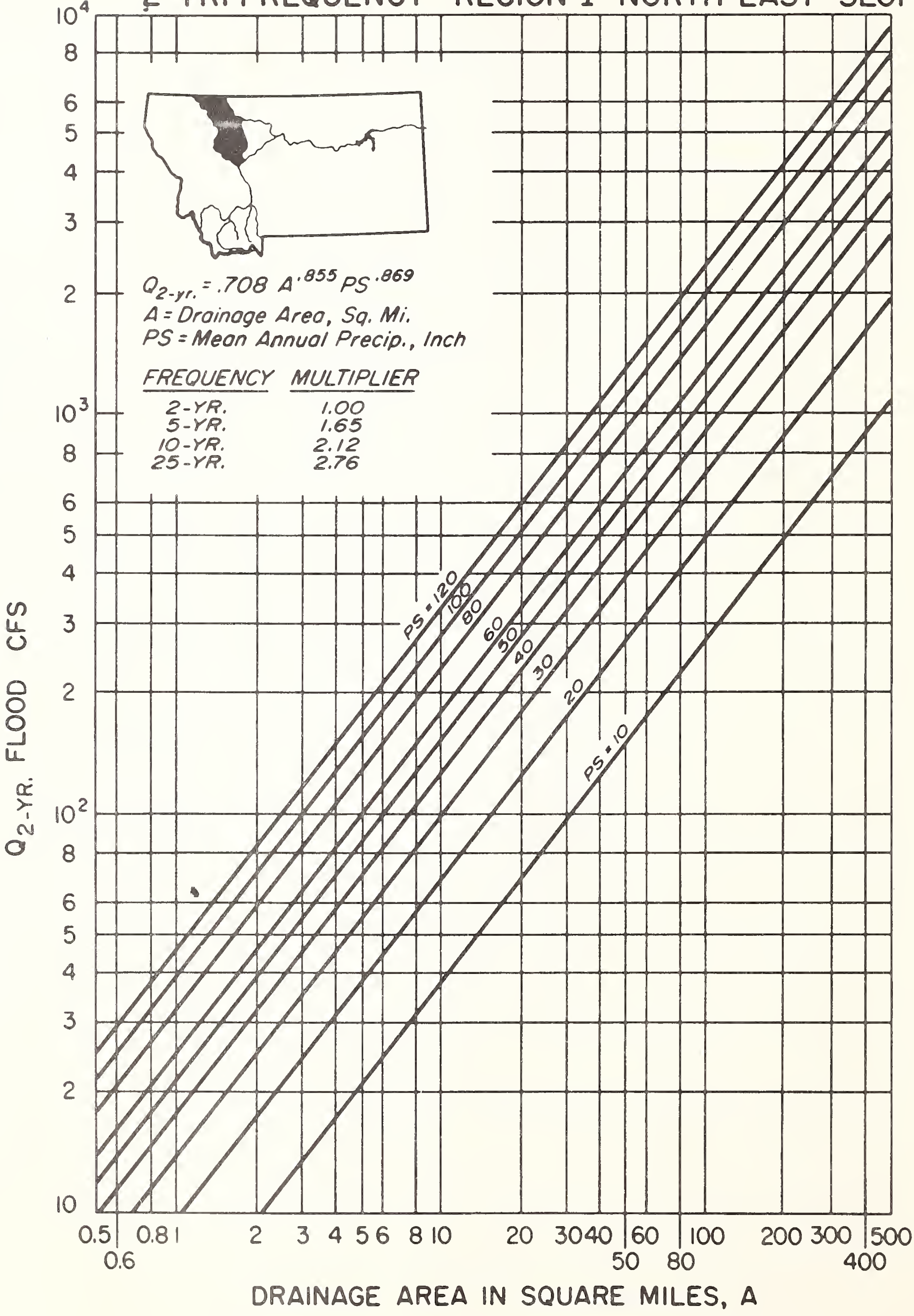


CHART 3.2

MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

50-YR. FREQUENCY REGION I NORTH EAST-SLOPE

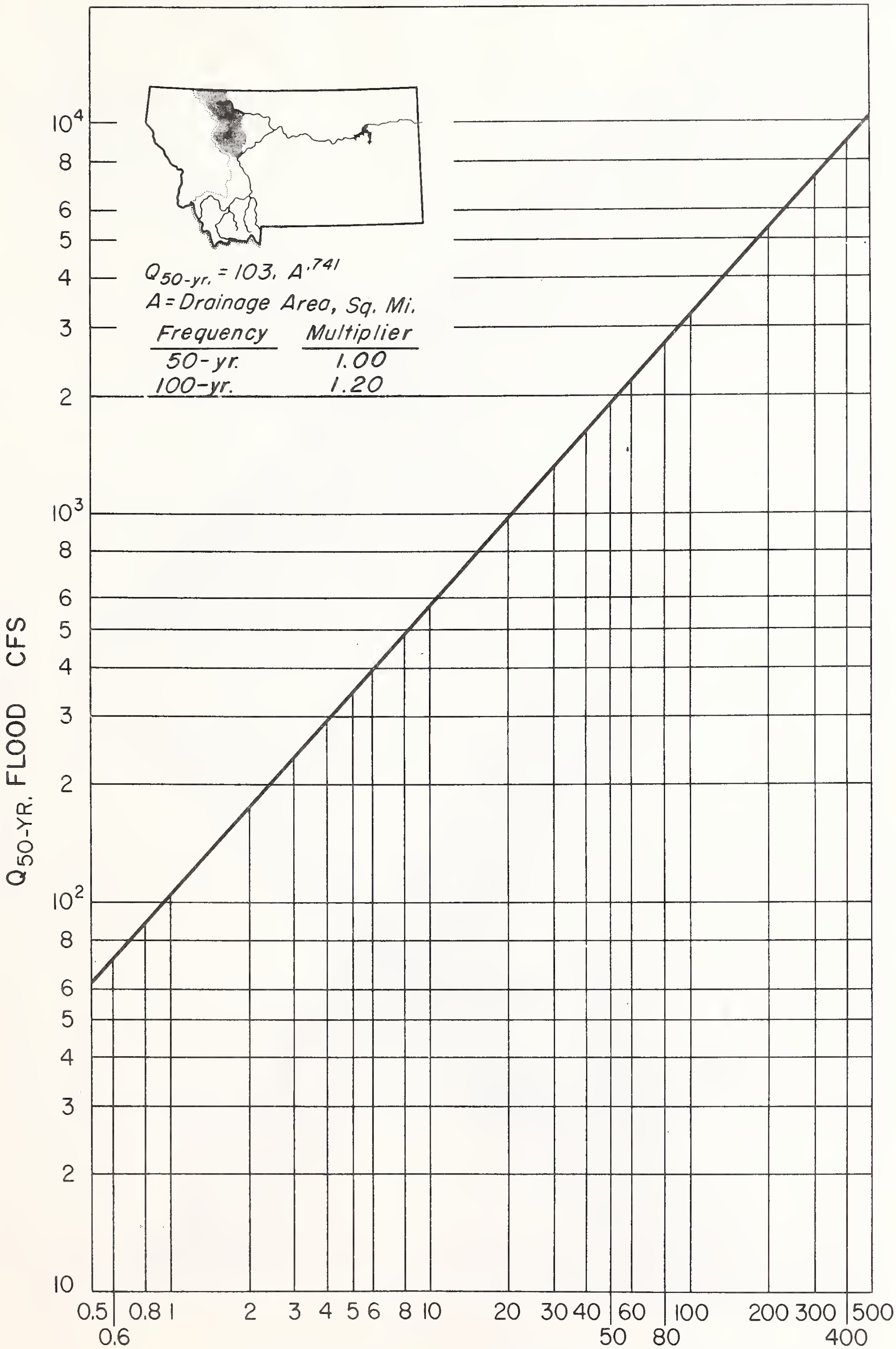
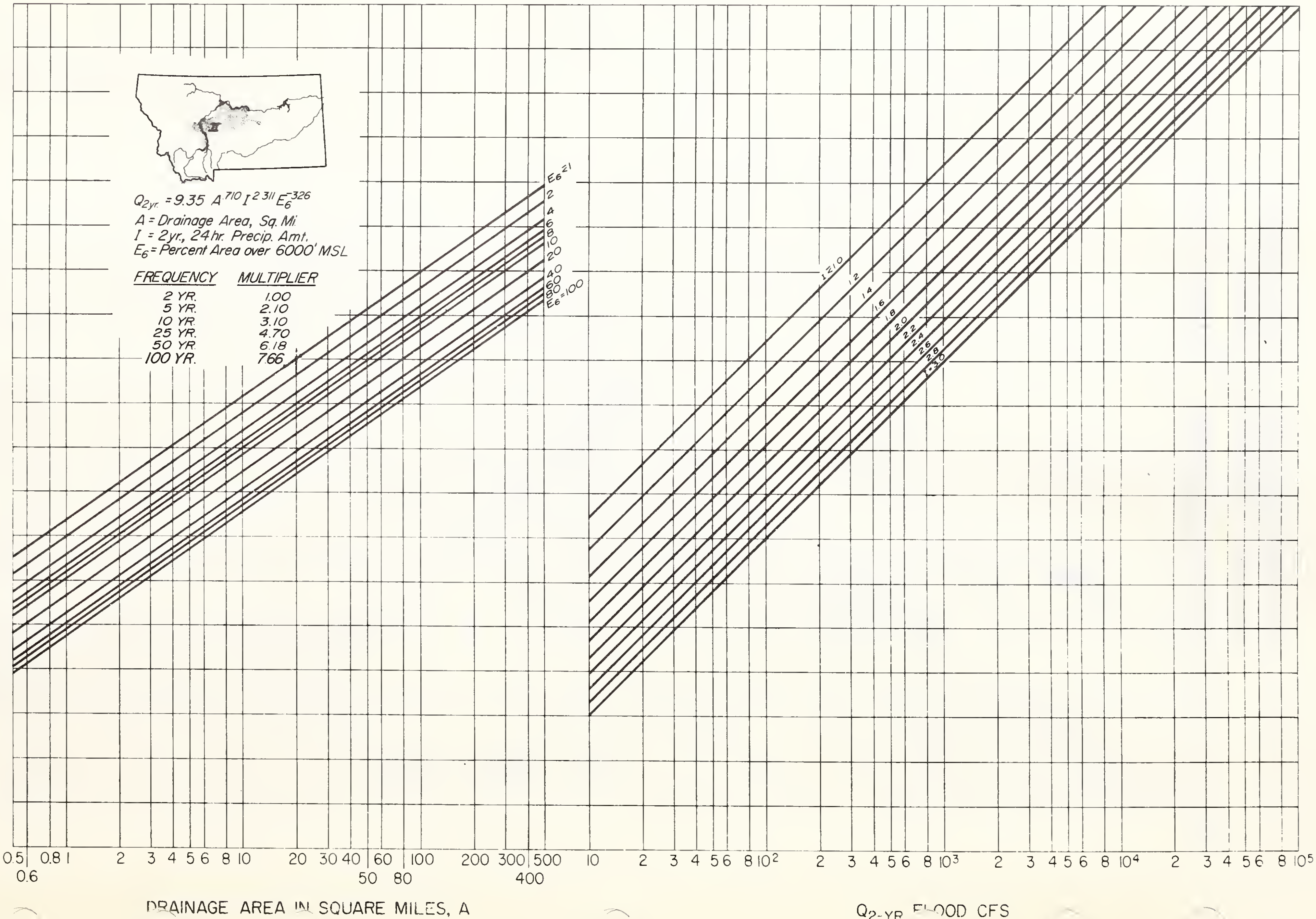


CHART 3.3

MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

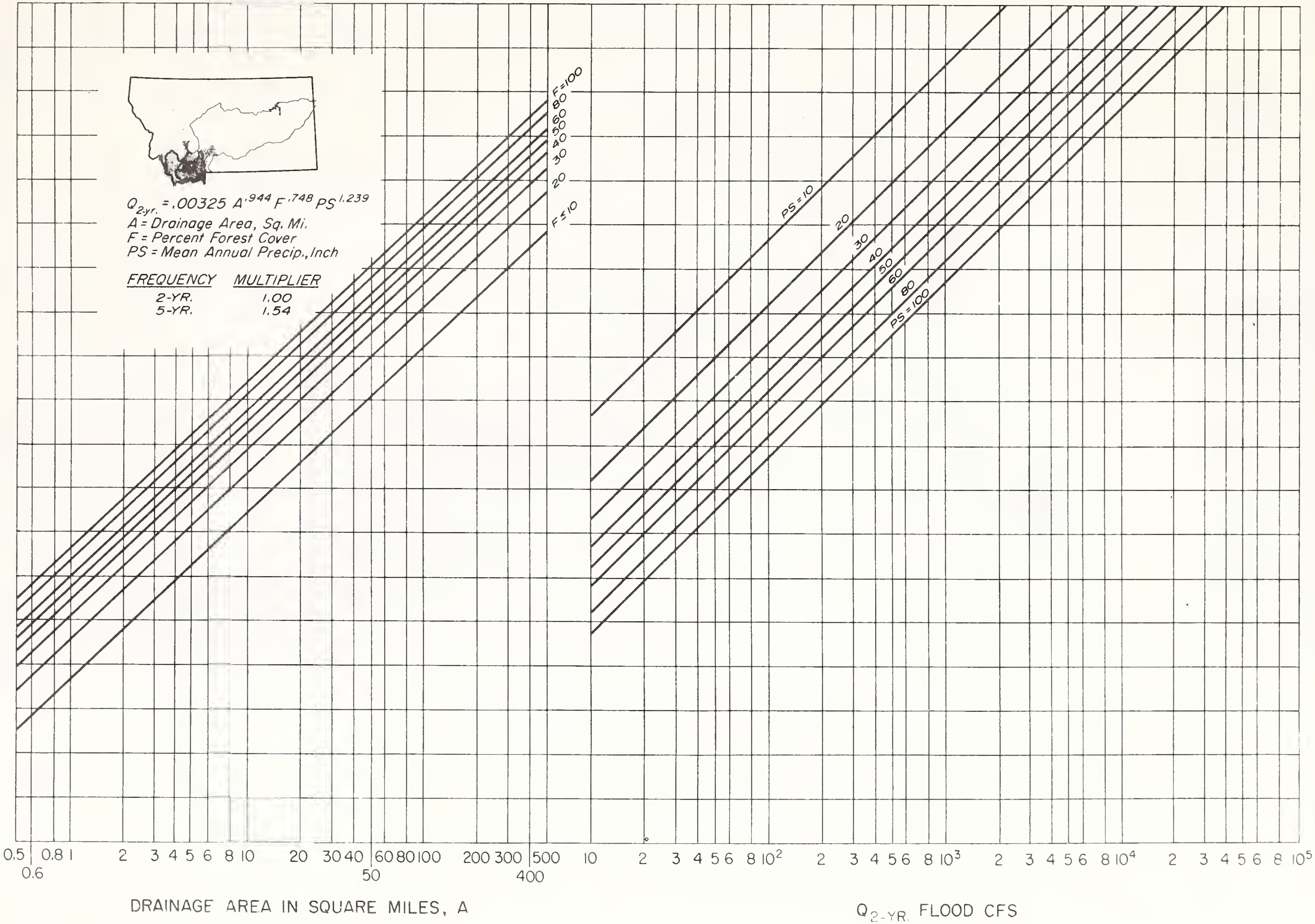
2-YR. FREQUENCY REGION II CENTRAL EAST-SLOPE



MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

2-YR. FREQUENCY REGION III SOUTHWEST

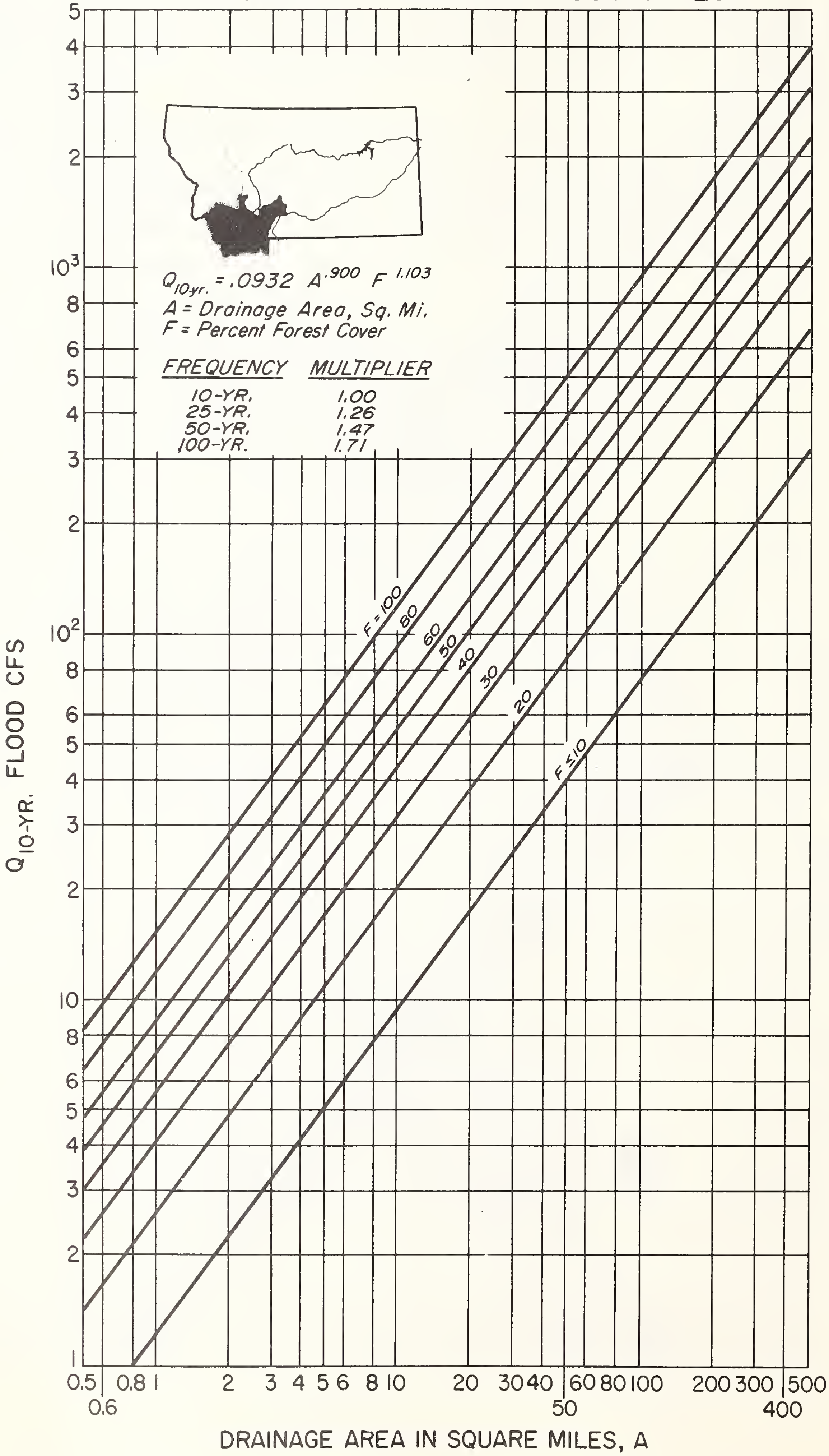
CHART 3.4



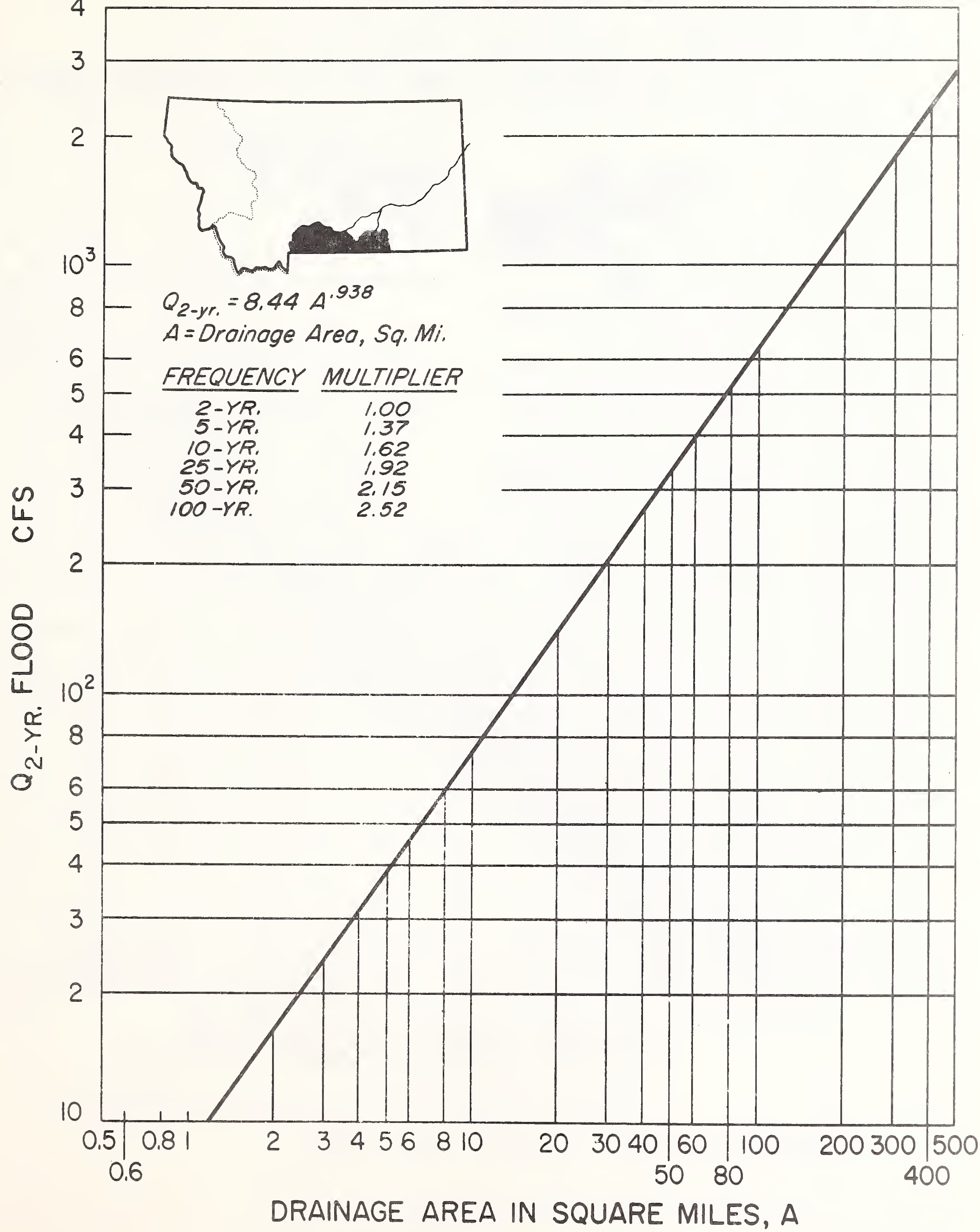
MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

CHART 3.5

10-YR. FREQUENCY REGION III SOUTHWEST

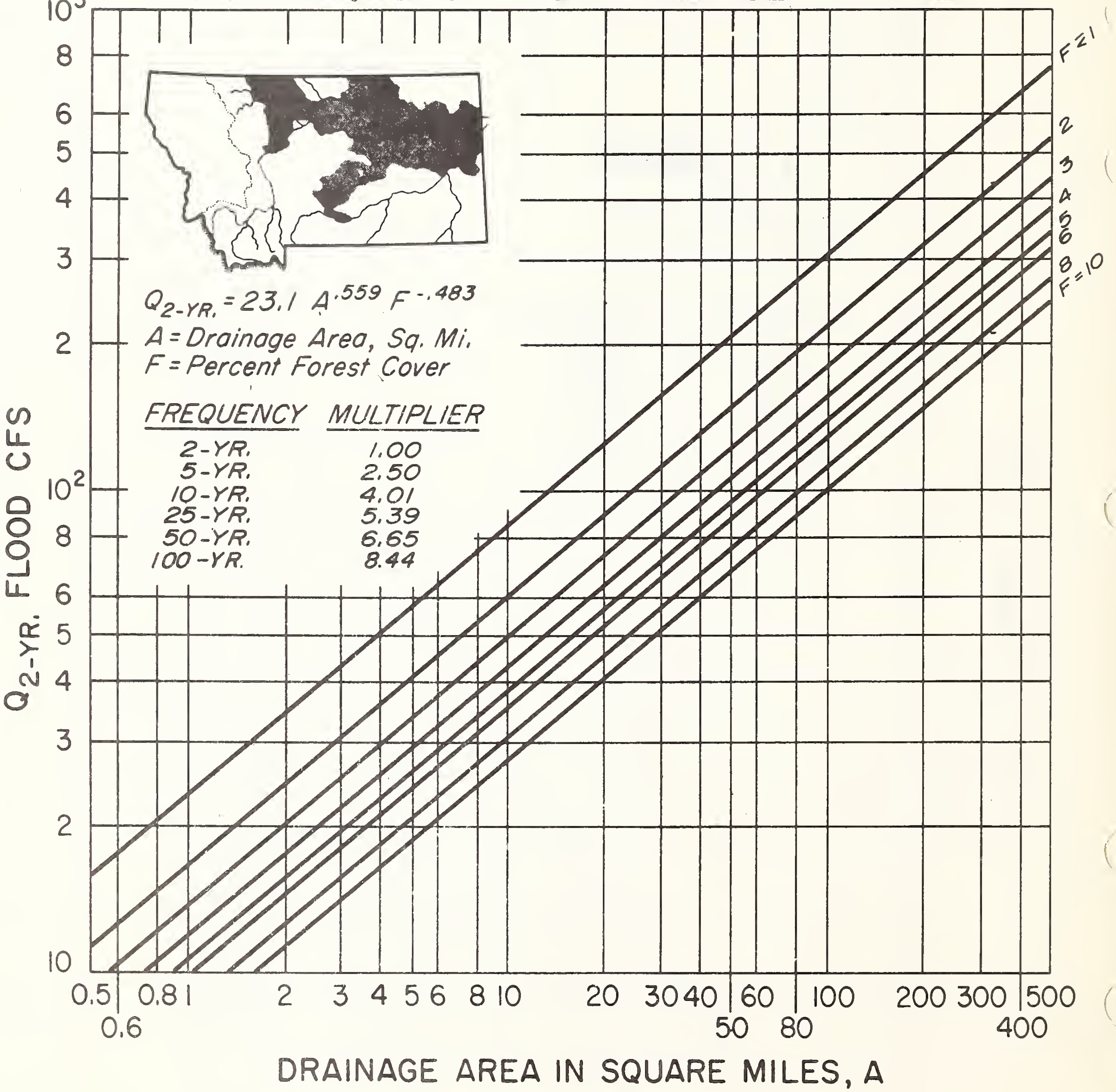


MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE
2-YR. FREQUENCY REGION IV SOUTH CENTRAL



MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

2-YR. FREQUENCY REGION V* CENTRAL-EAST

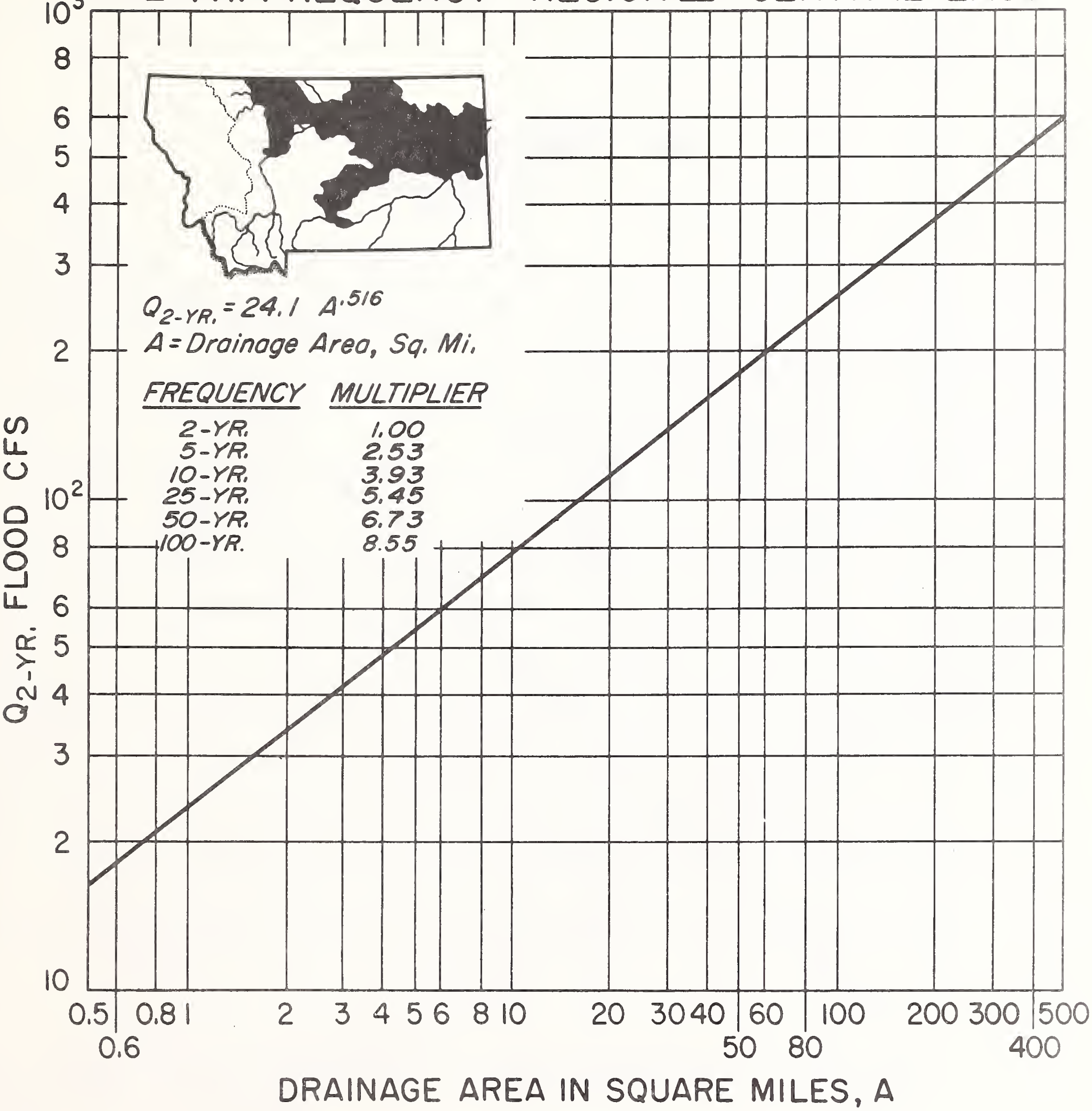


*Use this chart only if % forest is less than 9%

CHART 3.8

MONTANA HIGHWAY DEPARTMENT CULVERT DESIGN DISCHARGE

2-YR. FREQUENCY REGION V* CENTRAL-EAST



Use this chart only if % forest is greater than 9%

MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE
2-YR. FREQUENCY REGION VI NORTHERN

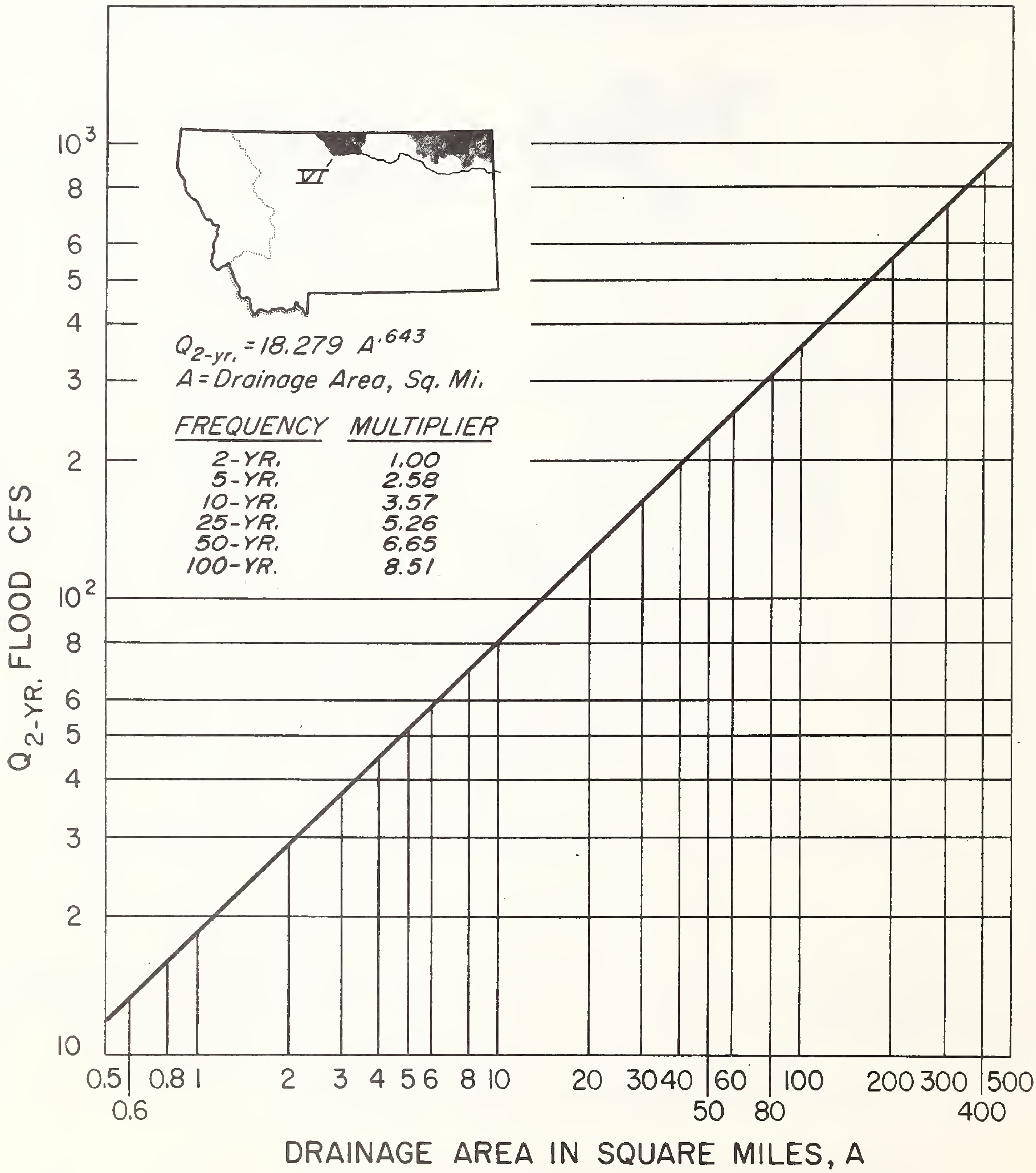
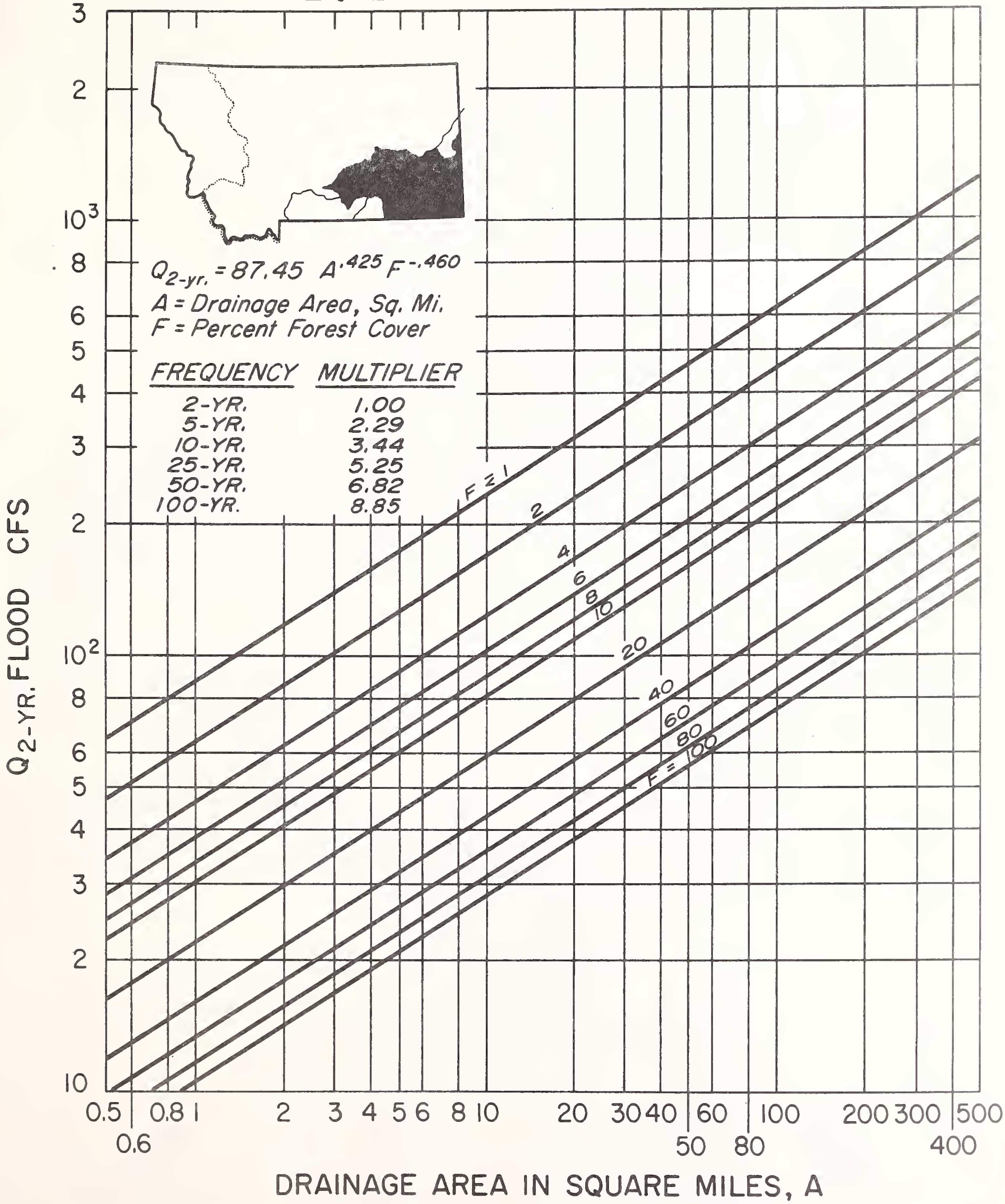


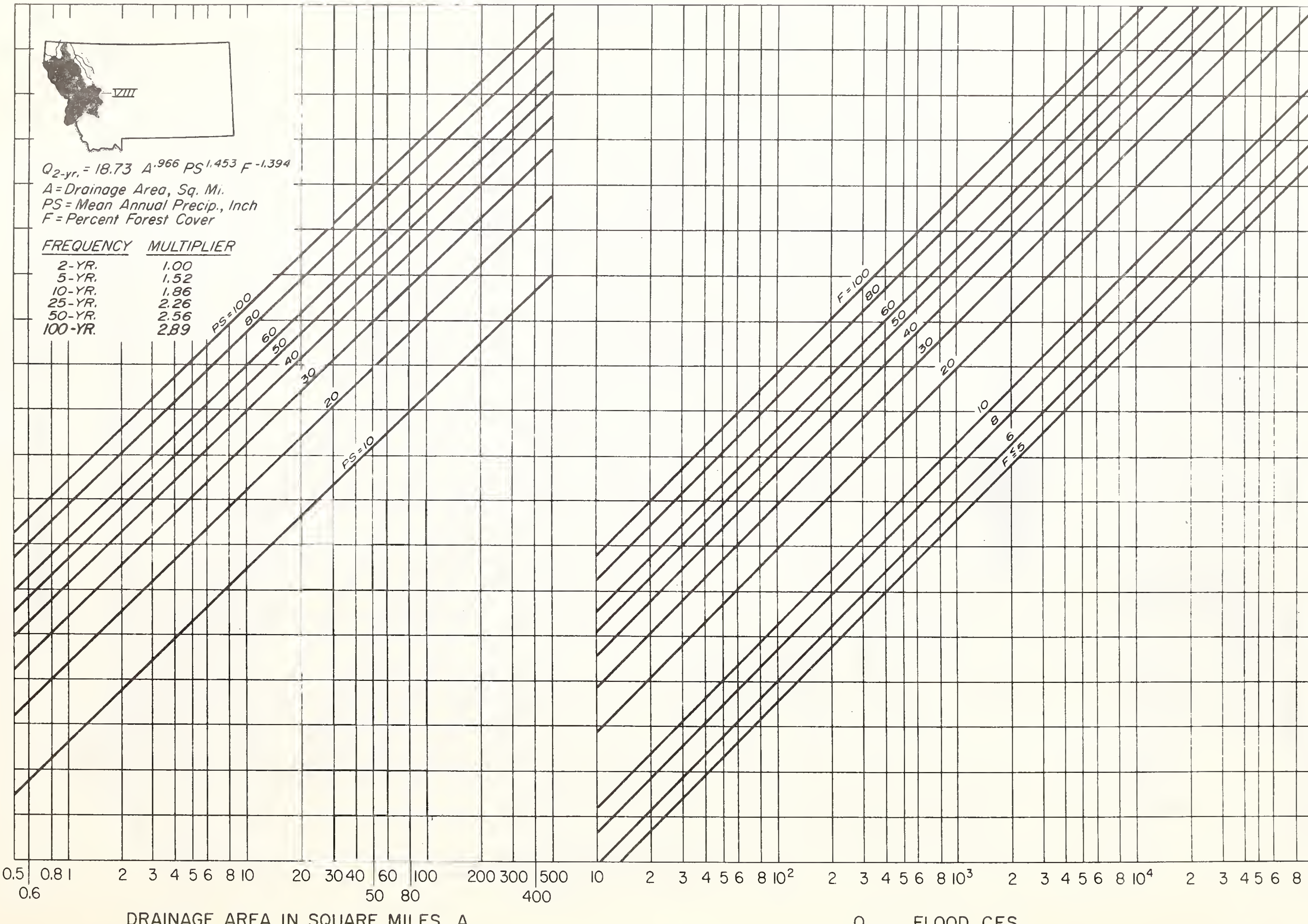
CHART 3.10

MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE
2-YR. FREQUENCY REGION VII SOUTHEAST



MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

2-YR. FREQUENCY REGION VIII COLUMBIA-SOUTH



MONTANA HIGHWAY DEPARTMENT
CULVERT DESIGN DISCHARGE

CHART 3.12

2-YR. FREQUENCY   REGION IX   COLUMBIA-NORTH

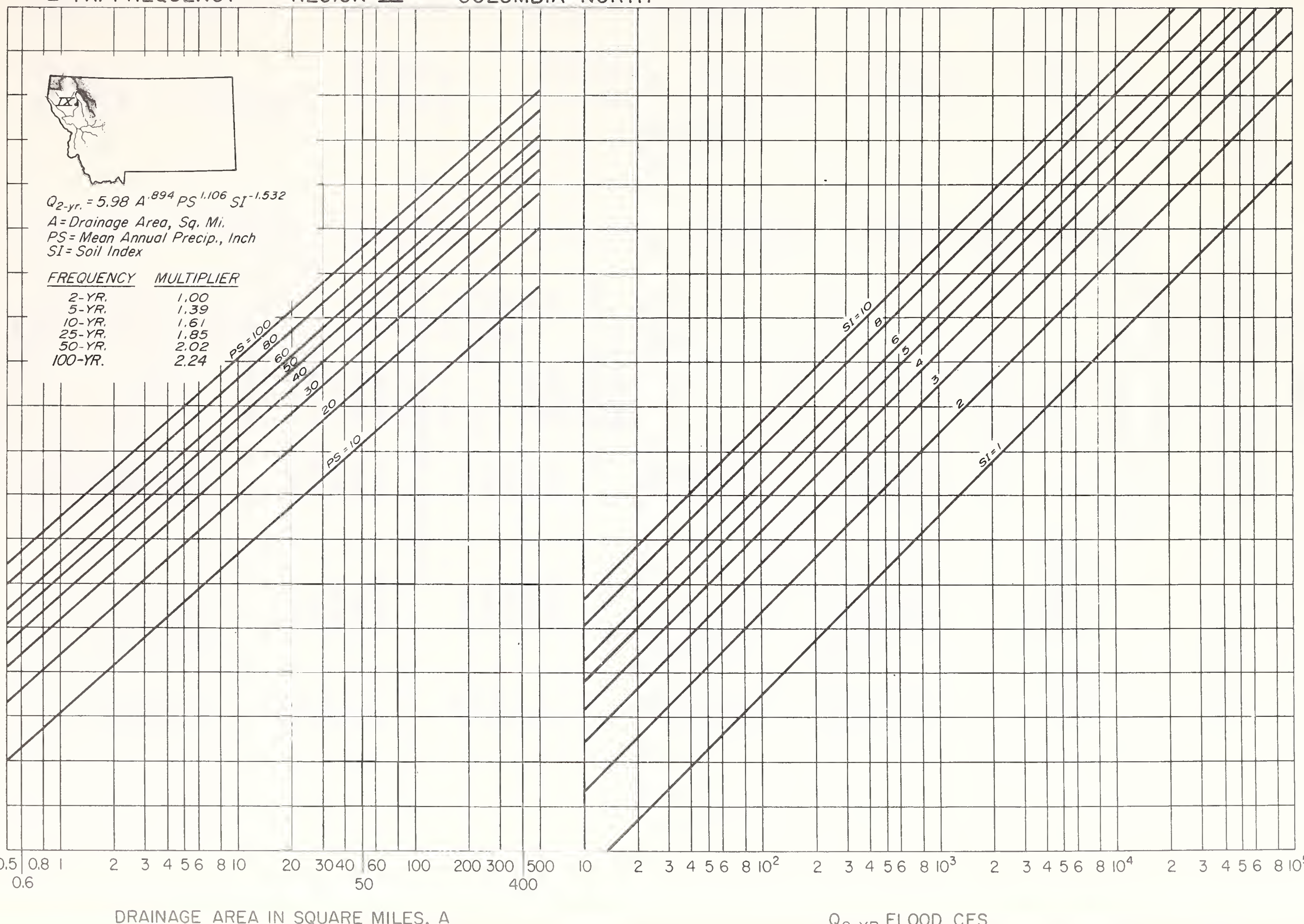


TABLE 3.3

Prediction Equations for
Various Recurrence Intervals

$$Q_1 = b_o X_1^{b_1} X_2^{b_2} \ldots X_n^{b_n}$$

(Individual Exponent Equations)

Flood	Regression Constant b_o	A	PS	F	SI	%>6000	I
		--Exponents $b_1 \ldots b_n$ for above variables --					
		REGION I					
Q_2	.0673	.920	1.414				
Q_5	.839	.862	.948				
Q_{10}	3.195	.834	.695				
Q_{25}	13.40	.805	.419				
Q_{50}	103.1	.741					
		REGION II					
Q_2	5.483	.724				-.162	2.295
Q_5	16.41	.716				-.293	2.406
Q_{10}	29.31	.709				-.347	2.371
Q_{25}	55.08	.703				-.400	2.284
Q_{50}	83.56	.695				-.427	2.201
		REGION III For % Forest > 19%					
Q_2	.00172	.970	1.390	.758			
Q_5	.00944	.919	1.087	.738			
Q_{10}	.0793	.911		1.131			
Q_{25}	.1549	.877		1.061			
Q_{50}	.2301	.855		1.023			
		Alternate Equations if Forest is < 19%					
Q_2	.00356	.918	2.203				
Q_5	.190	.869	1.879				
Q_{10}	.0450	.843	1.715				
Q_{25}	.115	.811	1.536				
Q_{50}	.207	.791	1.427				
		REGION IV					
Q_2	4.57	1.045					
Q_5	9.46	.973					
Q_{10}	14.13	.932					
Q_{25}	21.98	.885					
Q_{50}	29.44	.854					

TABLE 3.3(cont.)

Flood	Regression Constant b_o	A	PS	F	SI	%>6000	I
		--Exponents b_1 ... b_n for above variables--					
		REGION V For Forest < 9%					
Q_2	27.04	.510		-.428			
Q_5	60.26	.547		-.471			
Q_{10}	84.62	.565		-.490			
Q_{25}	116.1	.581		-.508			
Q_{50}	138.8	.591		-.519			
		Alternate if % Forest > 9%					
Q_2	28.18	.472					
Q_5	62.97	.506					
Q_{10}	88.72	.521					
Q_{25}	122.0	.536					
Q_{50}	146.0	.545					
		REGION VI					
Q_2	14.89	.663					
Q_5	42.07	.634					
Q_{10}	59.16	.642					
Q_{25}	87.50	.638					
Q_{50}	109.6	.636					
		REGION VII					
Q_2	69.75	.484		-.434			
Q_5	188.8	.443		-.461			
Q_{10}	308.3	.421		-.467			
Q_{25}	509.3	.397		-.469			
Q_{50}	696.6	.382		-.469			
		REGION VIII For % Forest > 16%					
Q_2	2.415	1.00	1.708	-1.168			
Q_5	14.32	.975	1.528	-1.307			
Q_{10}	38.46	.961	1.433	-1.398			
Q_{25}	116.9	.948	1.331	-1.509			
Q_{50}	243.8	.940	1.266	-1.591			
		Alternate if Forest < 16%					
Q_2	.0852	.945	1.25				
Q_5	.344	.908	1.02				
Q_{10}	.700	.890	.888				
Q_{25}	1.54	.871	.742				
Q_{50}	2.55	.859	.646				
		REGION IX					
Q_2	1.064	.937	1.284		-1.099		
Q_5	5.133	.900	1.145		-1.397		
Q_{10}	10.23	.888	1.095		-1.560		
Q_{25}	23.28	.876	1.023		-1.754		
Q_{50}	38.39	.869	.982		-1.880		

3.42 REGIONAL FREQUENCY ANALYSIS

The Regional Frequency Analysis method of predicting flood peaks on ungaged streams is a combination of stochastic and parametric hydrology. Nearby gaged watersheds with hydrologic parameters similar to the watershed in question are analyzed by stochastic methods to determine their design floods and the results are then projected to the ungaged watershed to determine its design flood. This method is described below.

The drainage area, topography, soil characteristics, land use, and vegetative cover of the ungaged watershed should be determined as well as possible. Then several nearby gaged watersheds whose characteristics are very similar to those determined for the ungaged watershed and which have adequate years of record (usually 10 years or more) are chosen. The floods with the same recurrence interval as that desired for the ungaged watershed are determined for these stations using one of the stochastic methods outlined in Section 3.3. A plot of flood peak in cfs vs drainage area in square miles is made for each station on log - log graph paper. These points are then connected with a straight line that best describes the points. The design flood with the desired recurrence interval for the ungaged watershed can now be read directly from the graph using its drainage area.

The Regional Frequency Analysis Method of determining flood peaks is shown in the following example.

<u>Example</u>

Determine the 50 year flood for Ten Mile Creek where it crosses U.S. Highway 12 west of Helena.

Given: Drainage Area = 64 sq mi

Watershed Description = rugged mountainous terrain, 90% forest cover

A listing of USGS gaging stations is consulted and the following stations

chosen for our Regional Frequency Analysis. They are in the approximate vicinity and their watershed characteristics are similar to those of Ten Mile Creek.

Station Number	Stream Name and Location	Drainage Area
6-0625	Ten Mile Creek Near Rimini	32.7 sq. mi.
6-0630	Ten Mile Creek Near Helena	102 sq. mi.
6-0617	Jackson Creek Near East Helena	3.44 sq. mi.
6-6018	Crystal Creek Near East Helena	3.77 sq. mi.
6-0685	Little Prickly Pear Creek Near Marysville	44.4 sq. mi.
6-0619	McClellan Creek Near East Helena	33.2 sq. mi.

These stations and the point where the flood peak is desired are shown in Figure 3.4. The 50-year flood is determined at each station by the Gumbel and Log-Pearson methods using computer program "PF Basic". The computer printout of these computations follows Figure 3.4.

The results from the Gumbel method were selected for use in this example for simplicity. Normally the results from the two methods should be compared and those tending to agree with floods of records, etc. or a combination of both methods should be used.

The 50 year discharge versus the drainage area are plotted on log - log paper for each of these points. The straight line which best describes these points is drawn and the 50-year discharge for a drainage area of 64 sq. mi. can be read as 700 cfs.

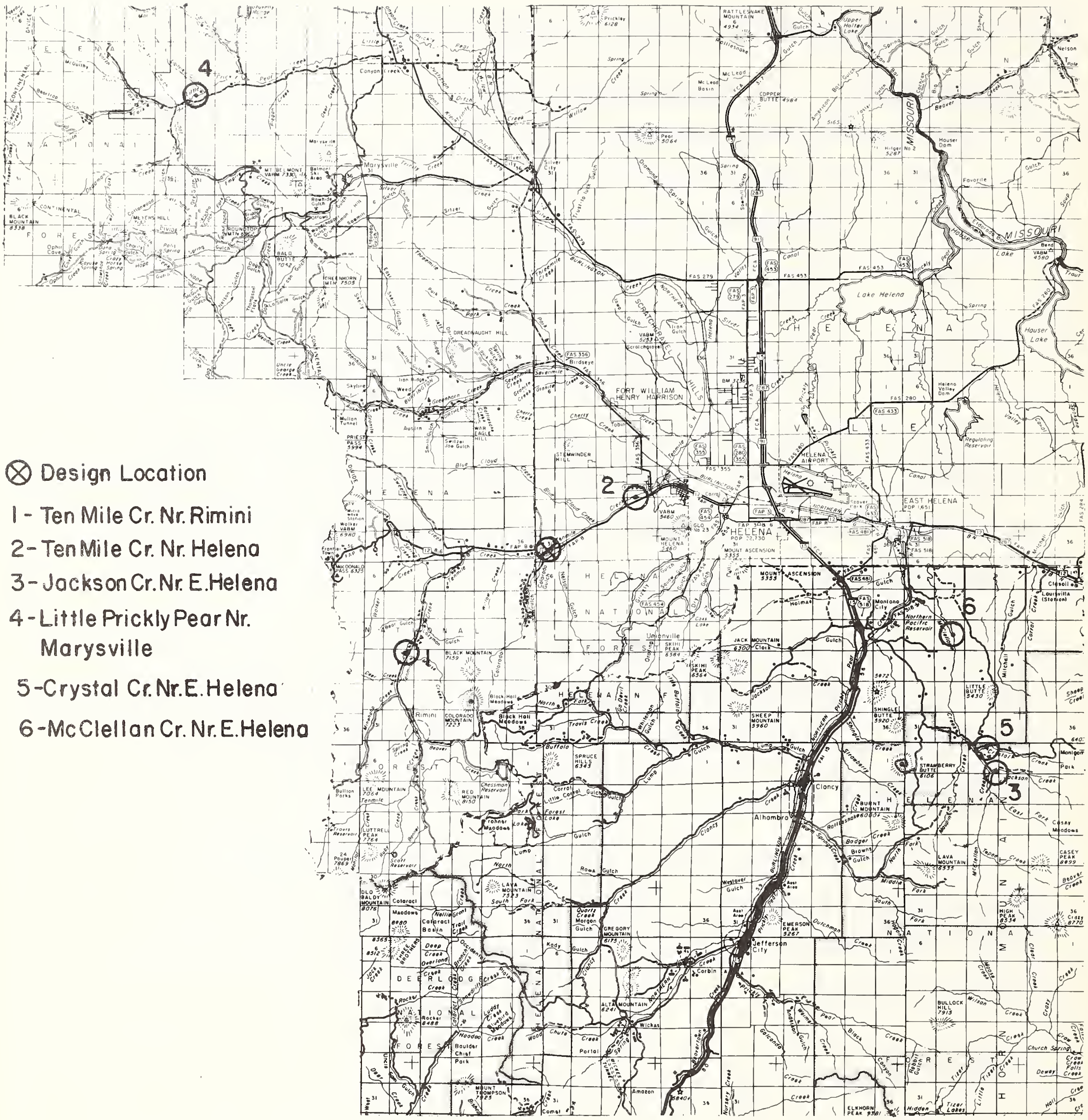


Figure - 3.4 — "Regional Frequency Analysis Example."

① TEN MILE CREEK NEAR RIMINI A=32.7

```
EDIT
       1420 data 471,296,781,172,80,299,373,385,173,367,173,200
EDIT   1421 data 703,249,400,179,41,195,258,143,81,66,134,490,136
EDIT   1422 data 96,209,242,297,253,231,73,338,403,107,319,289,242
EDIT   1423 data 469,111,145,219,145,216,202,274,186,222,176,556
EDIT   1424 data 246,142,320,278,308,218,177,204
EDIT   run

THE NUMBER OF YEARS IS
  ?   58

FREQUENCY                   GUMBEL METHOD          LOG PEARSON METHOD

100 YEAR                      708.0 CFS              708.6 CFS
 50 YEAR                      629.3 CFS              631.9 CFS
 25 YEAR                      550.0 CFS              553.3 CFS
 10 YEAR                      443.1 CFS
MEAN ANNUAL (2.33 YR)         254.6 CFS

EDIT
```

② TEN MILE CREEK NEAR HELENA A=102

```
EDIT   1420 data 477,85,548,995,456,230,405,328,424,486,186,76
EDIT   1421 data 440,398,211,165,340,865,404,450,257,37,140,250
EDIT   1422 data 129,106,83,86,654,108,95,169,248,325,340,360
EDIT   1423 data 80,449,399,113,355,329,250,774,132
EDIT   run

THE NUMBER OF YEARS IS
  ?   45

FREQUENCY                   GUMBEL METHOD          LOG PEARSON METHOD

100 YEAR                      983.8 CFS             1131.6 CFS
 50 YEAR                      867.9 CFS              978.6 CFS
 25 YEAR                      751.2 CFS              825.1 CFS
 10 YEAR                      594.0 CFS
MEAN ANNUAL (2.33 YR)         316.6 CFS

EDIT
```

③ JACKSON CREEK NEAR EAST HELENA A=3.44

```
EDIT   1420 data 4,16,12,19,14,7,20,17,15,10,9,9,4
EDIT   run

THE NUMBER OF YEARS IS
  ?   12

FREQUENCY                   GUMBEL METHOD          LOG PEARSON METHOD

100 YEAR                       27.6 CFS               24.3 CFS
 50 YEAR                       25.0 CFS               23.2 CFS
 25 YEAR                       22.4 CFS               21.9 CFS
 10 YEAR                       18.9 CFS
MEAN ANNUAL (2.33 YR)          12.7 CFS

EDIT
```

④ LITTLE PRICKLY PEAR NEAR MARYSVILLE A=44.4

```
EDIT  1420 data 315,196,180,204,454,124,29,155,160,224,84,149
EDIT  1421 data 114,149,303,238,146,121,29,110
EDIT  run

THE NUMBER OF YEARS IS
  ?   20
```

FREQUENCY	GUMBEL METHOD	LOG PEARSON METHOD
100 YEAR	478.9 CFS	408.2 CFS
50 YEAR	426.0 CFS	385.7 CFS
25 YEAR	372.7 CFS	357.8 CFS
10 YEAR	300.9 CFS	
MEAN ANNUAL (2.33 YR)	174.3 CFS	

EDIT

⑤ CRYSTAL CREEK NEAR EAST HELENA A=3.77

```
EDIT  1420 data 5,11,4,21,14,9,28,12,30,12,27,3,2
EDIT  run

THE NUMBER OF YEARS IS
  ?   12
```

FREQUENCY	GUMBEL METHOD	LOG PEARSON METHOD
100 YEAR	43.4 CFS	53.7 CFS
50 YEAR	38.4 CFS	46.5 CFS
25 YEAR	33.4 CFS	39.2 CFS
10 YEAR	26.6 CFS	
MEAN ANNUAL (2.33 YR)	14.7 CFS	

EDIT

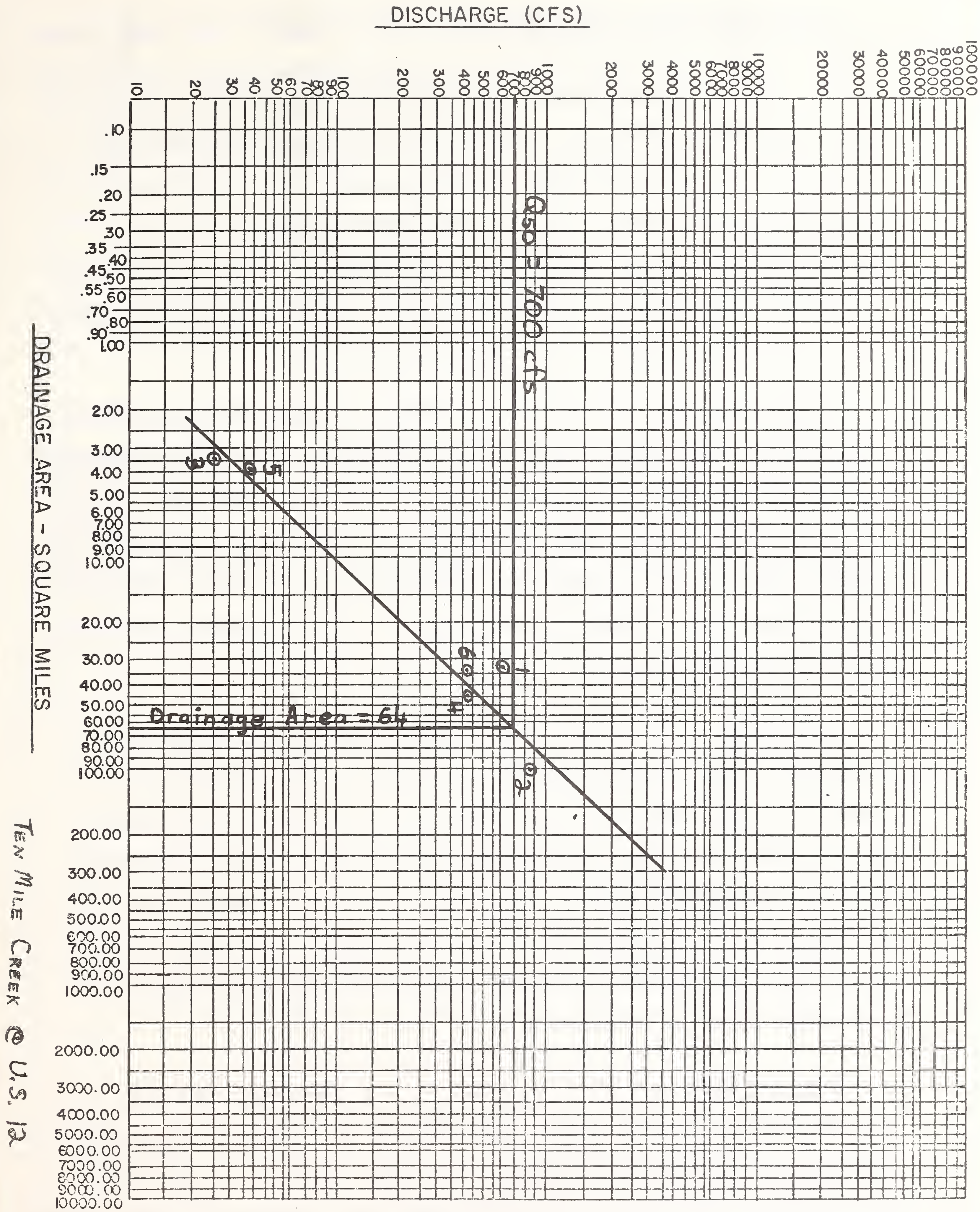
⑥ McCLELLAN CREEK NEAR EAST HELENA A=33.2

```
EDIT  1420 data 120,48,175,87,390,220,85,235,222,275,150,130,72,47
EDIT  run

THE NUMBER OF YEARS IS
  ?   13
```

FREQUENCY	GUMBEL METHOD	LOG PEARSON METHOD
100 YEAR	461.0 CFS	527.5 CFS
50 YEAR	410.5 CFS	460.8 CFS
25 YEAR	359.6 CFS	394.8 CFS
10 YEAR	291.0 CFS	
MEAN ANNUAL (2.33 YR)	170.0 CFS	

EDIT


DISCHARGE (CFS)
DRAINAGE AREA - SQUARE MILES
Q50 = 700 cfs
Drainage Area = 64
Ten Mile Creek @ U.S. 12

3.43 OTHER PARAMETRIC METHODS

Several other methods of predicting floods from Montana drainages have been presented in recent years. All of these studies were done by the U.S. Geological Survey using flood data from gaged watersheds to develop magnitude - frequency equations. Because none of these methods were based on as many gaging stations or as many years of record as used by Dr. Dodge, it generally is felt that the equations developed by Dodge are superior. These other methods are discussed briefly below for information purposes only.

V. K. Berwick - V. K. Berwick in his "Floods In Eastern Montana - Magnitude and Frequency", published in 1958 presented a method for determining the magnitude and frequency of floods from drainage areas of 100 to 3000 square miles for that portion of eastern Montana averaging roughly east of 109 degrees longitude. His regional frequency curve is based upon the analysis of 14 watersheds using the Gumbel extreme value probability distribution. His only parameters are drainage area and mean basin elevation.

F. C. Boner - Fred C. Boner in his "Interim Report on the Frequency And Magnitude of Floods in Eastern Montana", published in 1963, presented his composite flood frequency curves based upon the more extensive flood records then available. The area covered by this study extended slightly further west than the area covered by Berwick. Boner used 21 long term recording stations to develop his flood frequency curves. Boner used drainage area, average elevation of the main stream channel, the meander length of the main stream course, and a geographical factor as his parameters.

Boner and Omang - In 1967 F. C. Boner and R. J. Omang published their Open-file report entitled, "Magnitude and Frequency of Floods From Drainage Areas Less Than 100 Square Miles In Montana". This report covered all of the State and presented a method for determining the magnitude of floods with 10 and 25-year recurrence intervals. They used 283 stations with 5 years or more of record to

develop their flood frequency curves. The average annual runoff, the drainage area, and the location of the watershed are the parameters used in their study.

Water-Supply Paper 1687 - The "Water-Supply Paper 1687", published in 1964 by the Geological Survey presents a method for determining flood flows for that portion of Montana drained by the Columbia River. This method can be used for drainage areas from 20 to 10,000 square miles. Drainage area, mean annual runoff, % area of lakes and ponds and a geographical factor are the variable parameters used in this method.

Water-Supply Paper 1679 - "Water-Supply Paper 1679" is similar to "Water-Supply Paper 1687" but it covers that portion of Montana drained by the Missouri River and its tributaries. The flood prediction method presented in this paper is valid for drainage areas of 10 to 5000 square miles. This method has drainage area and mean altitude as its parameters.

References

1. Berwick, V. K., Floods in Eastern Montana Magnitude and Frequency, Open File Report, U.S. Geological Survey, Water Resource Division, Helena, Montana, May, 1958, in cooperation with the Montana Highway Commission.

2. Bodhaine, G. L., and D. M. Thomas, Magnitude and Frequency of Floods in the United States, Part 12 Pacific Slope Basins in Washington, and Upper Columbia River Basin, U. S. Geological Survey Water-Supply Paper 1687, prepared in cooperation with the Washington State Department of Highways, 1964.

3. Boner, F. C., Frequency and Magnitude of Floods in Eastern Montana, U.S. Geological Survey, Helena, Montana, November, 1963, in cooperation with the Montana Highway Commission.

4. Boner, F. C. and R. J. Omang, Magnitude and Frequency of Floods from Drainge Areas Less Than 100 Square Miles in Montana, Open File Report, U.S. Geological Survey, Helena, Montana, 1967.

5. Dodge, E. R., Final Report Application Hydrologic and Hydraulic Research to Culvert Selection in Montana, Volume I and II, 1972, for the Montana Department of Highways, in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

6. Patterson, J. L., Magnitude and Frequency of Floods in the United States, Part 6-A Missouri River Basin above Sioux City, Iowa, U.S. Geological Survey Water-Supply Paper 1679, 1966.

7. Williams, T. T., Final Report Drainage Correlation Research Project, Volume I and II, 1971, for the Montana Highway Commission in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

SECTION 3.5
RATIONAL METHOD

3.5 RATIONAL METHOD OF RUNOFF PREDICTION

Introduction

Over the years many formulas have been developed for estimating peak rates of discharges from watersheds. Of these the so called rational formula is probably the best known. Although hydrologists have known for at least 40 years that such formulas have little validity for natural watersheds, they are still widely used.

The rational formula is,

$$Q = CiA$$

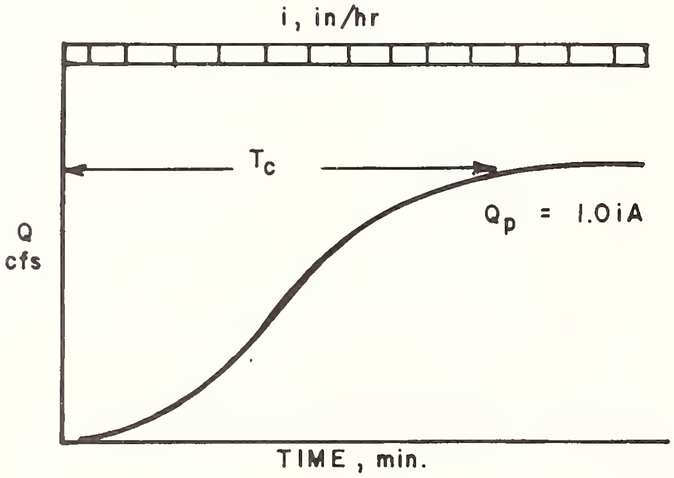
where

- Q = Peak discharge, cfs
- C = Coefficient of runoff
- i = Rainfall intensity (inch/hr) for a duration equal to the travel time of the watershed (i is customarily read from a rainfall intensity-frequency-duration curve).
- A = Drainage area, acres

The units of the rational formula are based on the relation 1 cfs = 1 acre-inch/hr, which is accurate to within 1%.

The rational formula is presently being used by approximately 90% of all state highway departments to predict flood peaks, although ostensibly such use is primarily for small relatively impervious drainage areas. The reasons for the continued use of this formula despite its failure to adequately model the runoff process are evident in its simplicity. Values of i and A are easily and routinely determined. C values can be read from many published tables. Hence calculations of Q from the rational formula can be performed with utter simplicity by practically anyone. It is important that engineers and technicians considering the use of the rational formula understand the full meaning of each term along with the basis of the formula.

The basis for the rational formula is developed by considering the following special case. This involves the analysis of a constant intensity rain falling on an area for which C = 1.0 (actually such rainfalls rarely if ever occur and no such areas exist), for a period of time greater than T_c, assumed here equal to the time required for equilibrium conditions to be established. See Section 3.53, Time of Concentration, for further discussion of T_c. The resulting runoff hydrograph would be similar to that shown in Figure 3.5.



T_c = time to equilibrium, assumed

= time of concentration (min)

Q_p = peak flow (cfs)

A = drainage area (acres)

i = constant rainfall intensity (in/hr)

Figure 3.5 Runoff Hydrograph for Constant Intensity Rainfall on Impervious Surface

As indicated, the peak flow rate is given by $Q_p = 1.0\ iA$. Furthermore, it should be noted that Q_p is the maximum possible peak flow which will occur if the rainfall rate occurs at the constant rate i in/hr.

It is evident from the hydrograph that Q_p does not occur until the storm duration equals the time when 100% of the drainage area first contributes runoff, which is called the time of concentration of the drainage area, T_c. Thus if the storm duration is less than T_c, the flood peak will be less than Q_p.

3.51 COEFFICIENT OF RUNOFF

The coefficient of runoff C is a multiplier with value 0.0-1.0 which supposedly indicates the percentage of the rainfall rate i which will appear as surface runoff from the drainage area A. The primary shortcoming associated with the coefficient of runoff is that it neglects the surface and channel storage of rainfall excess required in the runoff process. The use of a constant C value for a particular drainage area assumes that the processes of infiltration, retardation, and evapo-transpiration are constant for all recurrence interval rainstorms for that watershed. Actually it is quite obvious that for most natural watersheds the coefficient of runoff is indeed highly variable and not capable of being accurately predicted. In addition there is no physical reason why the percent of excess rain rate, averaged over the travel time of the watershed, should be directly proportional to the peak rate of flow for the outflow hydrograph. One recent investigation has completely abandoned the pretense that C is a runoff coefficient, and referred to it as complex stochastic function which maps rainfall rates into runoff rates.

However, in the case of small, relatively impervious areas, such as paved surfaces, it becomes possible to predict C with greater reliability. Also, because of the short travel time and limited surface and channel storage involved, equating the average rate of excess water supply to the peak rate of discharge may be more realistic. In these cases C will probably have an average value in the range .85-.95, since it will be true that all the rainfall on a highly impervious area will appear as runoff - except that required to wet the surface and fill depression and channel storage.

Table 3.4, can be used to estimate the runoff coefficient for various types of surfaces.

3.52 RAINFALL INTENSITY

In using the rational formula it is always assumed that the design rainfall intensity is read from the intensity-duration-frequency chart at the duration corresponding to T_C, the time of concentration of the drainage area. There is, of course, no reason to believe that peak floods are produced by rain storms of constant intensity. The rainfall intensity read from the chart actually represents the maximum rainfall rate averaged over the time period T_C which occurs during any such time period of a rainstorm of recurrence interval T_p years.

By recurrence interval we mean the average number of years which from a probability standpoint may be expected to occur to the first storm with an intensity equal to or greater than that specified. In civil engineering, this is referred to as average return period or simply recurrence interval. The magnitude of the event, here a rainfall intensity, is often referred to as the T_p year rainstorm or event. The term is generally misunderstood by layman (and unfortunately by others) when it gives the impression that there will be T_p years between such events, when in fact the probability of such an event occuring in any year, which is simply $1/T_p$, remains constant independent of the occurrence of such an event in the previous year or during any recent year.

The time period T_C does not really represent the duration of the rainstorm, or any definite chronological time period in a given rainstorm. It is only a rainfall averaging time period, and for a particular rainstorm the design intensity may occur anywhere during the storm from the start of the cessation of rain. The time of concentration is defined as the time required for all points within the drainage to be contributing runoff to the inlet of the drainage structure. The time of concentration is discussed in detail in Section 3.53.

In 1969, the U.S. Weather Bureau-Environmental Science Services Administration (ESSA) published a series of revised storm rainfall maps of Montana for durations from 6 hours to 24 hours and recurrence intervals from 2-years to 100-years. Figure 3.3, shows the 2-year recurrence interval 24-hour duration map of this series. From this map one may determine the amount or intensity of storm rainfall to be expected at any point in Montana for the 2-year recurrence interval. The isopluvial lines shown are in tenths of an inch, thus at Billings a storm with total rainfall of 1.4 inches in 24-hours (read on Figure 3.3 has a recurrence interval of 2-years which means a probability of occurring in any given year of 1/2. (Probability = 1/recurrence interval).

From a careful study of the 1969 ESSA maps and U. S. Weather Bureau Technical Paper No. 40 it was found that intensity-duration data for any station in Montana could be reasonably represented in each of four geographic regions by the regional charts shown in Figues 3.8 to 3.11. On Figure 3.7, the heavy dashed lines denote the approximate four regional boundaries. The use of these regional intensity-duration charts is explained in Section 3.55.

3.53 TIME OF CONCENTRATION

The standard procedure in the design of hydraulic structures is to assume that the averaging time to be used for rainfall intensity is equal to the time of concentration T_c of the drainage area. Here T_c is taken to mean the largest combination of overland flow time and channel flow time which exists from anywhere in the basin to the outlet or design point. Except for steady state conditions, there is really no logical reasoning to support this assumption.

Steady state conditions rarely, if ever, occur in an actual rainstorm. Hydrologic research in recent years has shown considerable variation associated with T_c for a given watershed. For example, experimental evidence has been collected which strongly suggests that T_c is not constant but rather is related (nonlinearly) to the magnitude of the flood event itself.

In another recent study it was proposed that the duration of the design intensity should in fact be set equal to the numerical average of all observed T_c values for a given drainage area. This represents an attempt to regard T_c as a random variable rather than a constant.

Although studies such as these represent progress toward a better understanding of the rainfall-runoff process, there is little advancement being made toward developing better methods of estimating T_c for ungaged drainages. Therefore, to predict T_c, the designer generally relies upon the methods and assumptions used for many years. The assumption that the rainfall intensity to be used in the rational formula should correspond to a duration (averaging time) equal to T_c is still recommended.

Rainfall intensity is read from the Intensity-Duration-Frequency chart for the region in which the design area is located. The duration at which i is read on the chart is equal to the time of concentration T_c of the drainage area. T_c is assumed to be the overland flow time plus channel flow time for the portion of the drainage area most remote (timewise) from the design point. Since velocity of flow depends upon Q, which in turn depends on i, an iterative (successive approximation) solution is necessary. A trial value of i may be assumed, from which approximate Q and overland channel flow time are calculated. With an approximate value of T_c thus determined, a revised value of i is read from the rainfall chart. Overland flow and channel flow times are determined as follows:

<u>Overland Flow Time</u> - For small plots with relatively plane surfaces and without defined channels, such as highway pavements and medians, and built-up drainage areas, the Izzard equation for time to equilibrium t_e in minutes is

$$t_e = \frac{41bLo^{1/3}}{(Ci)^{2/3}} \qquad (1)$$

where

$$b = \frac{.0007i+Cr}{S_o{}^{1/3}} \qquad (2)$$

where

L_o = length of overland flow, ft

C = coefficient of runoff

i = design rainfall intensity, inch/hr

C_r = coefficient of retardance, see Table 3.4 below

TABLE 3.4

Values of C_r in Eq. (2)

Surface	Value of C_r
Smooth asphalt	.007
Concrete pavement	.012
Tar & gravel pavement	.017
Closely clipped sod	.046
Dense bluegrass turf	.060

Eq. (1) is valid when the product of iL_o is less than 500. Although such instances will be rare, where iL_o does exceed 500, Eqs. (3) and (4) may be used

$$t_e = \frac{b'L_o{}^{.6}}{(C_i)^{.4}} \qquad (3)$$

where

$$b' = 1.2\frac{n^{.6}}{S_o{}^{.3}} \qquad (4)$$

which are based on kinematic wave theory and the Manning equation, with n the familiar Manning roughness coeffiecient (See Table 4.32).

If the drainage area has irregular surface topography rather than essentially flat surfaces, the Kirpich equation is suggested as an alternate method of estimating t_e. This empirical relation,

$$t = \frac{.00013 L_o^{.77}}{S_o^{.385}} \qquad (5)$$

may be solved numerically or by the Kirpich nomograph in Figure 3.6. All terms are as previously defined.

The Kirpich equation does not include the rainfall intensity i, but assumes that t_e is constant for any given drainage area, irrespective of rainfall rate. A comparison of the Kirpich equation with other empirical equations for estimating t_e shows that it tends to give conservative results (i.e. Kirpich produces comparatively low t_e values).

Channel Flow Time - If defined flow channels, such as gutters, ditches, or pipes, are included in the design, the designer must also estimate the travel time for flow in such channels. A common method of obtaining channel flow time is to divide the channel length L_c by the mean velocity of flow when the channel is at the bankfull stage. This method obviously is a simple approximation of the spatially varied channel flow phenomenon and should be used with caution if the drainage area exceeds 10 acres. To be conservative the designer may wish to use only about 2/3 of the value calculated in this manner. The Manning equation is suggested to estimate the mean channel velocity.

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where

V = mean velocity, ft/sec

n = Manning n

R = hydraulic radius = A/WP

(A = cross section area, WP = wetted perimeter)

S = slope energy grade line (for uniform flow slope channel bed)

A comprehensive tabulation of n values, and nomographs for graphical solution

of the Manning equation are presented in Section 4.6, Open Channel Flow.

3.54 SUMMARY EVALUATION

The application of the rational formula to estimate flood peaks from natural watersheds should be done only as a last resort when other methods cannot be applied. It is important that the designer be aware that the rational formula, even when applied to fairly impervious areas, has virtually no theoretical justification. Moreover, the designer should realize that he must contend with at least four types of uncertainties when applying rational formula. These are as follows:

1. Uncertainty associated with the selection of the runoff coefficient C.
2. Uncertainty due to the effects of the temporal and areal distribution of the design rainfall intensity.
3. Uncertainty that the actual peak discharge occurs when 100% of the drainage area is contributing runoff at the design point.
4. Uncertainty as to the true recurrence interval of the flood peak which is predicted by the rational formula. (The predicted peak will not necessarily have the same recurrence interval as the rainfall intensity from which the flow is calculated.)

Despite the failure of the rational method to really take into account the nature of the rainfall-runoff process, many engineers still believe with considerable logic, that for relatively impervious areas of small size, (less than 10 acres), it provides a reasonable basis for flood estimates. However, it is not recommended that the rational formula be applied to pervious natural watersheds. Typical examples of areas to which the rational formula might be applied are highway pavements and shoulders, highway medians, and urban or residential areas.

3.55 DESIGN PROCEDURE

The design procedure presented here is an outline only. The previous discussions should be reviewed for a through understanding of the rational equation. It is strongly recommended that the designer become familiar with these discussions so that he can develop an awareness of the shortcomings and limitations of the rational method for calculating flood peaks.

To use the rational formula to predict the peak runoff, the designer should follow the procedure outlined below.

1. Determine the following drainage area parameters:

   a. Drainage area A, acres

   b. Length of overland flow L_o, ft

   c. Length of channel flow, L_c, ft

   d. Channel slope S_c, ft/ft

   e. Average slope of overland flow surface S_o, ft/ft

2. From the characteristics of the drainage area estimate the coefficient of runoff from the tabulation presented in Table 3.5.

3. Determine the time of concentration T_c for the drainage area and the design rainfall intensity i in inch/hr for the desired recurrence interval. The method for determining the time of concentration T_c is given in Section 3.53. The rainfall intensity is determined from Figures 3.7 to 3.11. The area intensity-duration chart to be used is determined from Figure 3.7. The family of parallel lines shown on the regional intensity-duration charts of Figures 3.8 to 3.11. are guidelines defining the trend of intensity vs. duration for that region. To determine the 2-year intensity to be expected for any duration one enters the charts at the 24-hour duration with the 2-year 24-hours intensity in inch/hour calculated by dividing the amount read from Figure 3.7 by 24.. The 2-year intensity at any desired duration is determined by moving parallel to the curved

guidelines and reading the ordinate at this duration. To obtain the rainfall intensity for this duration for the design recurrence interval, one uses the table of multipliers on the chart.

4. With values of C, i, and A now determined we calculate the estimated flood peak from the rational formula as

$$Q = CiA$$

where Q = Peak discharge, cfs

C = coefficient of runoff

i = Rainfall intensity corresponding to time of concentration of drainage area, inch/hour

A = Drainage area, acres

3.56 TABLES AND FIGURES

TABLE 3.5

Coefficient of Runoff - C
For Use Rational Formula

$$Q = C\ i\ A$$

Roofs		.75	.95
Pavements			
Portland Cement, Asphaltic Concrete		.80	.95
Bituminous, open graded or cracked		.70	.95
Gravel Roadway			
From clean & loose to clayey & hard		.25	.70
Earth, bare to dense grass or vegetation			
Flat (2%), Steep (7%)			
Sandy, from uniform size to fines	Bare	.15	.50
AHO flat, to graded, some	Light vegetation	.10	.40
silt AHO clay and steep	Dense vegetation	.05	.30
Loam, from sandy or gravely AHO	Bare	.20	.60
Flat, to clayey and steep	Light vegetation	.10	.45
	Dense vegetation	.05	.35
Gravel, from clean AHO loose and	Bare	.25	.65
flat, to high silt or clay AHO steep	Light vegetation	.15	.50
Clay, from sandy or silty AHO	Bare	.30	.75
flat, to dense clay AHO	Light vegetation	.20	.60
Steep	Dense vegetation	.15	.50
Railroad Yards		.10	.30
Composite Urvan Areas			
Business Blocks			
Densely built		.70	.95
Moderately built, some open space		.50	.70
Residential blocks			
Suburban		.25	.40
Single family, dense		.30	.50
Multiple family, detached		.40	.60
Multiple family, continuous		.60	.70
Apartments		.50	.70
Industrial Blocks			
Light, some open space		.40	.80
Densely built		.60	.90
Parks, Golf courses, Cemeteries		.10	.30
Playgrounds		.20	.45
Unimproved Land		.10	.30
Highway Slopes and Ditches			
See earth, bare to dense grass or vegetation			

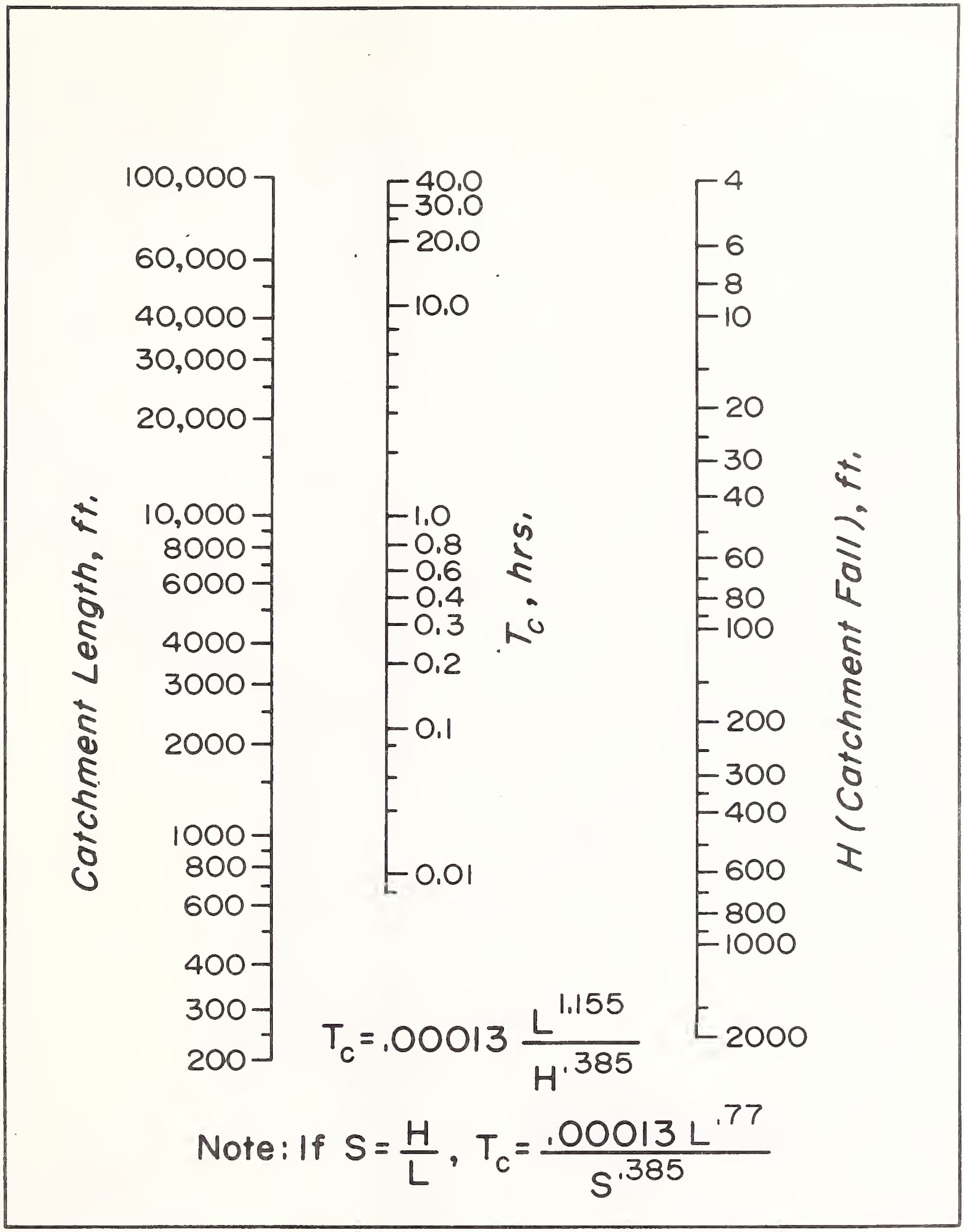
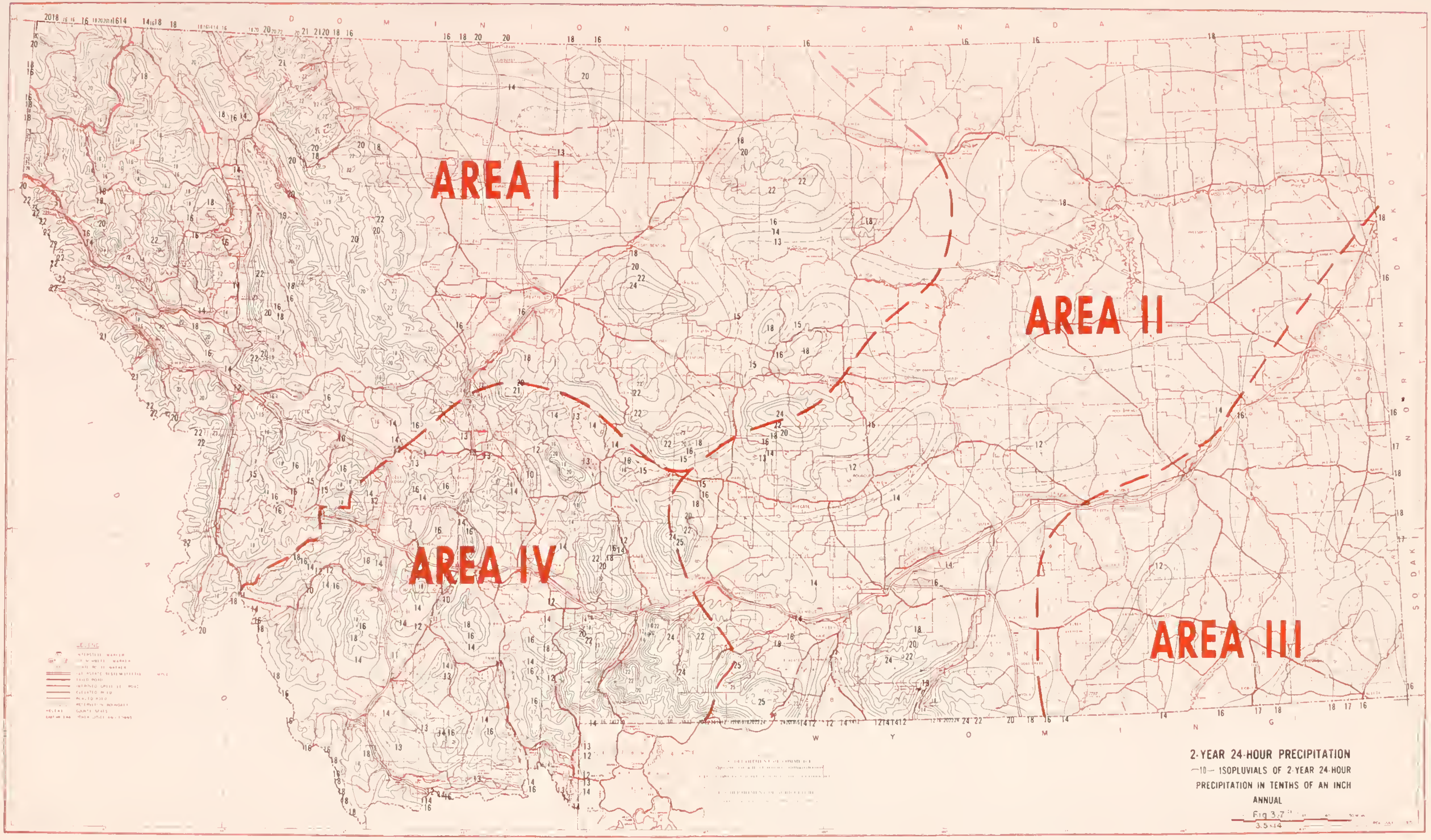


Fig.3.6 Kirpich Nomograph for Estimating Time of Concentration, T_c


AREA I
AREA II
AREA III
AREA IV
D O M I N I O N O F C A N A D A
W Y O M I N G
N O R T H D A K O T A
SO DAK
2-YEAR 24-HOUR PRECIPITATION
—10— ISOPLUVIALS OF 2-YEAR 24-HOUR PRECIPITATION IN TENTHS OF AN INCH
ANNUAL
Fig 3.7
3.5-14

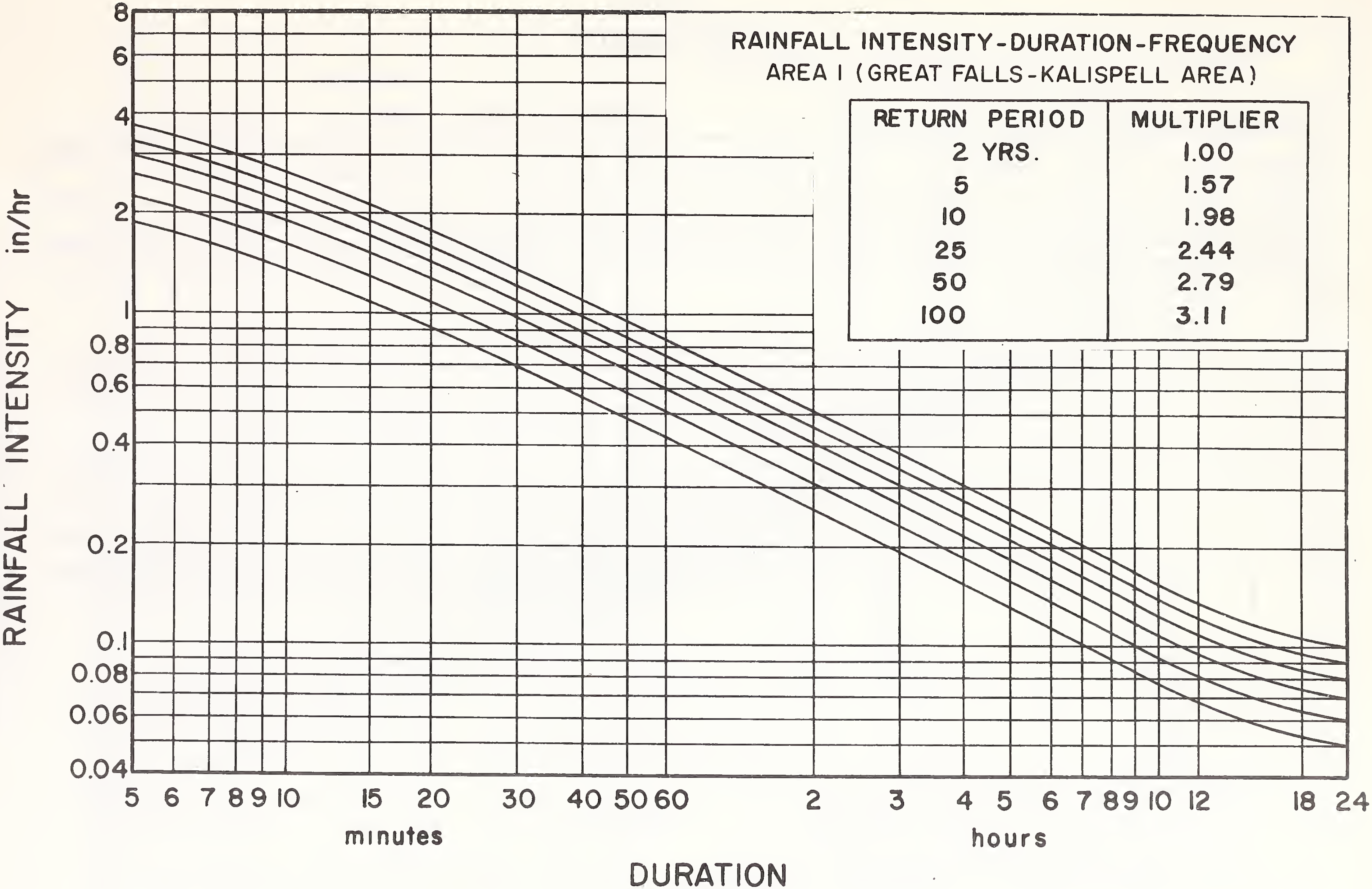


Fig. 3.8 Rainfall Intensity-Duration-Frequency Chart Area I, Montana

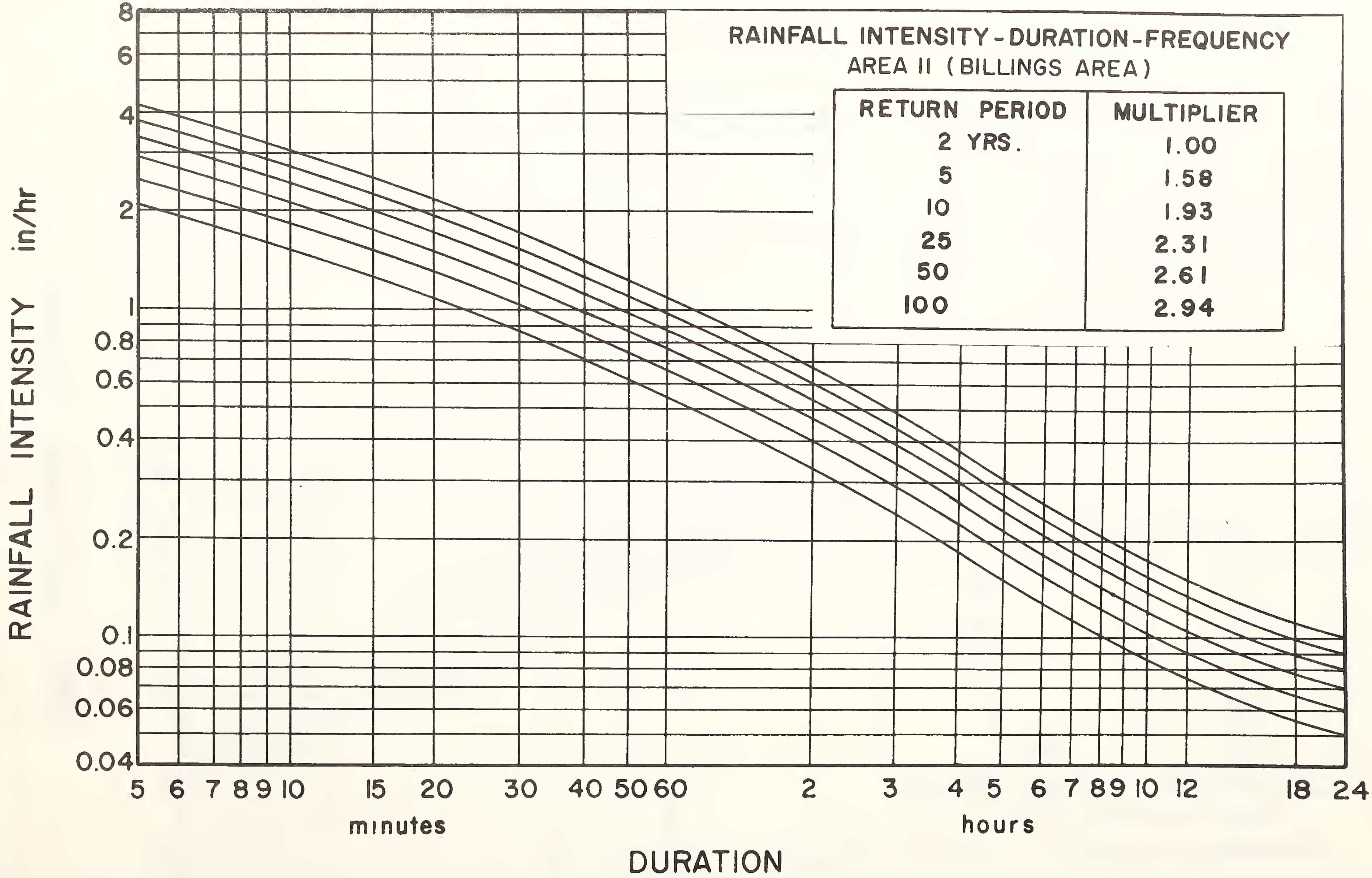

RAINFALL INTENSITY-DURATION-FREQUENCY
AREA II (BILLINGS AREA)
RETURN PERIOD | MULTIPLIER
2 YRS. 1.00
5 1.58
10 1.93
25 2.31
50 2.61
100 2.94
RAINFALL INTENSITY in/hr
8
6
4
2
1
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
5 6 7 8 9 10 15 20 30 40 50 60
minutes
2 3 4 5 6 7 8 9 10 12 18 24
hours
DURATION

Fig.3.9

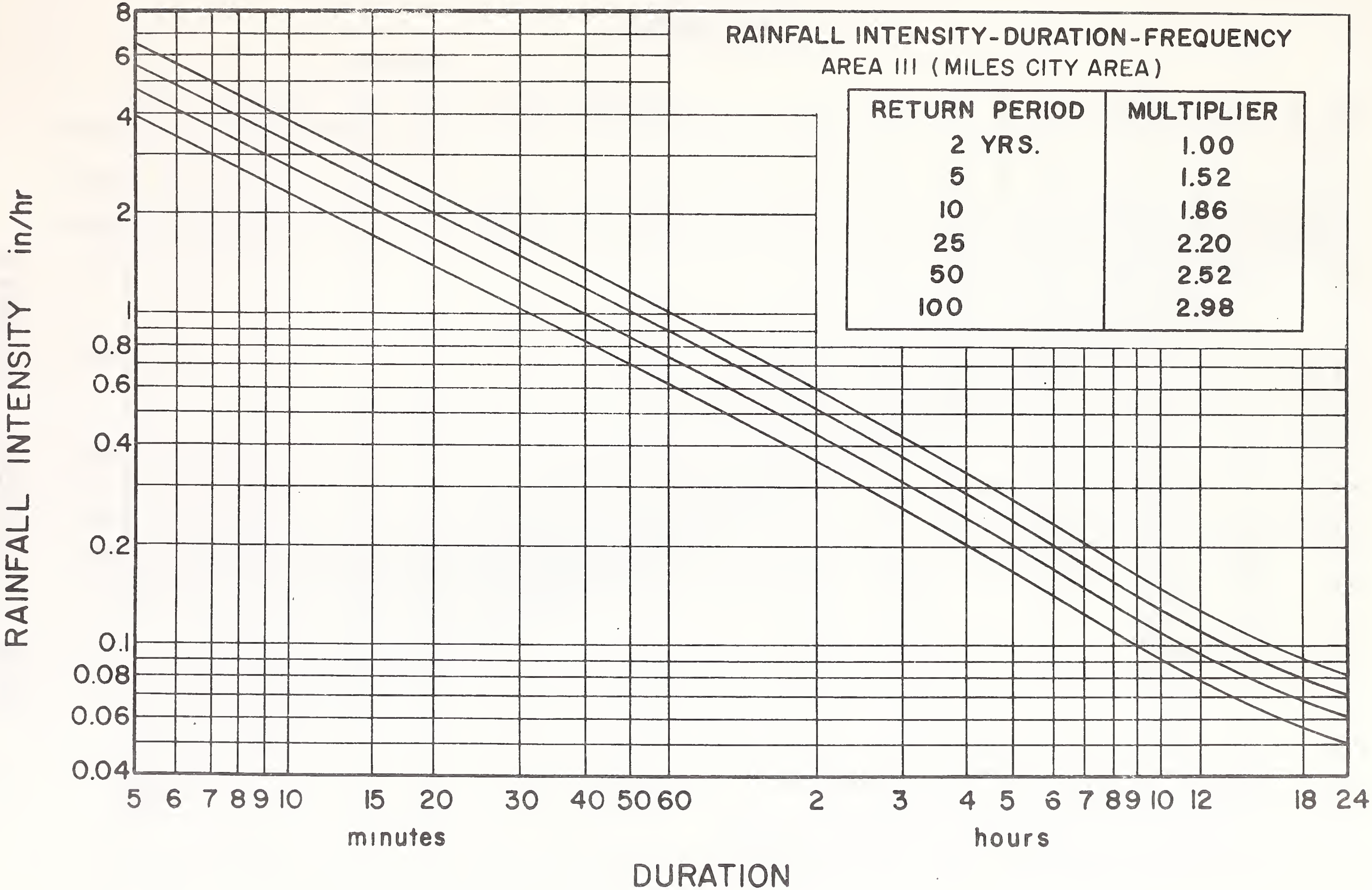

RAINFALL INTENSITY-DURATION-FREQUENCY
AREA III (MILES CITY AREA)
RETURN PERIOD
MULTIPLIER
2 YRS.
1.00
5
1.52
10
1.86
25
2.20
50
2.52
100
2.98
8
6
4
2
1
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
RAINFALL INTENSITY in/hr
5 6 7 8 9 10 15 20 30 40 50 60
minutes
2 3 4 5 6 7 8 9 10 12 18 24
hours
DURATION

Fig. 3.10

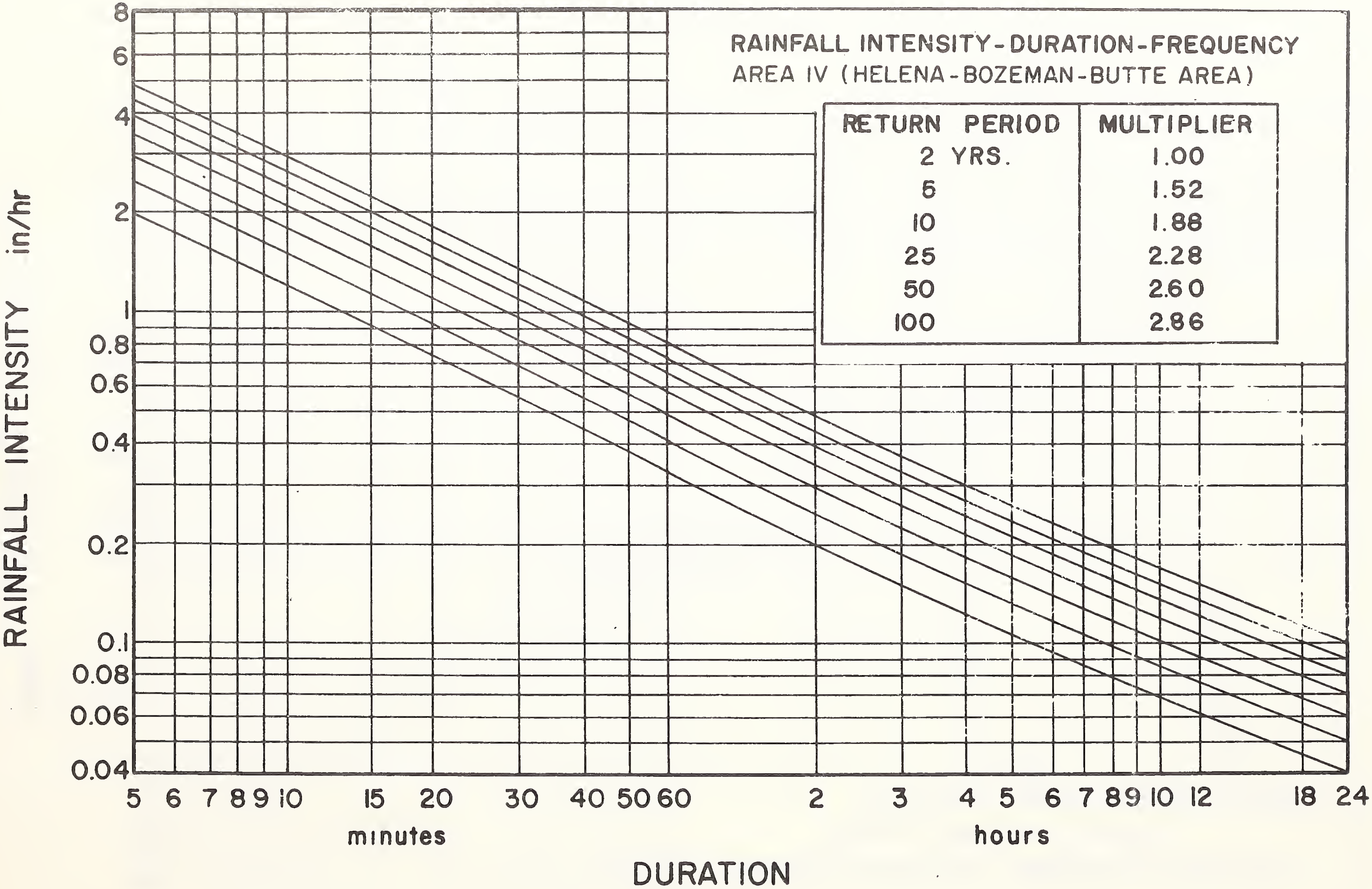

RAINFALL INTENSITY-DURATION-FREQUENCY
AREA IV (HELENA-BOZEMAN-BUTTE AREA)
RETURN PERIOD
2 YRS.
5
10
25
50
100
MULTIPLIER
1.00
1.52
1.88
2.28
2.60
2.86
RAINFALL INTENSITY in/hr
8
6
4
2
1
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
5 6 7 8 9 10 15 20 30 40 50 60
minutes
2 3 4 5 6 7 8 9 10 12 18 24
hours
DURATION

Fig. 3.11

References

1. Dodge, E. R., Final Report Application Hydrologic and Hydraulic Research to Culvert Selection in Montana, Volume I and II, 1972, for the Montana Department of Highways, in cooperation with U.S. Department of Transportation, Federal Highway Administration.

2. Technical Paper No. 40, Rainfall Frequency Atlas of the U.S., January, 1963, Washington, D.C.

REVISED TECHNIQUES FOR ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS IN MONTANA

U.S. GEOLOGICAL SURVEY

Open-File Report 81-917

Prepared in cooperation with the
MONTANA DEPARTMENT OF HIGHWAYS,
FEDERAL HIGHWAY ADMINISTRATION,
U.S. FOREST SERVICE, and the
U.S. BUREAU OF LAND MANAGEMENT

Front cover photographs: Flooding of tributaries to the Yellowstone River in southeastern Montana, May 19, 1978. Photographs by U.S. Bureau of Reclamation.

MONTANA DEPARTMENT OF HIGHWAYS
Helena, Montana 59620

MEMORANDUM

TO: Holders of Montana Department of Highways Hydraulic Manual

FROM: Stephen C. Kologi, P.E., Chief, Preconstruction Bureau

RE: Hydraulics Manual Update

DATE: November 4, 1981

Under a cooperative agreement, the U.S. Geological Survey has completed a report providing revised techniques for estimating magnitude and frequency of floods in Montana. We are hereby providing you with a copy of this report (Open-File Report 81-917) which is to be incorporated into the Hydraulics Manual provided you about six years ago.

We are unable to completely update the Hydraulics Manual at this time or provide copies of all the materials referenced below; however, this material is to be incorporated into the manual as follows:

a. Note in Section 3.3 that Log-Pearson Type III is used following the procedures outlined in the United States Water Resources Council's Bulletin #17A, "Guidelines for Determining Flood Flow Frequency." By this reference Bulletin #17A shall be incorporated into the Hydraulic Manual.

b. Note in Section 3.4 that references to the Dodge Method are to be replaced with the methods of Open-File Report 81-917.

c. Users of the Hydraulic Manual shall become familiar with the limitations of the regression equations presented in the Open-File Report and as discussed on page 16 of the report.

d. As in the past, the Hydraulics Manual does not attempt to show which flood prediction method is most appropriate for any given area or stream site but merely presents the methods commonly used. Users must exercise sound hydrologic judgment when evaluating each individual site.

e. We hope to be able to provide an update to the manual in the near future which will provide guidance on the requirements of FHPM 6-7-3-2. Until that time, FHPM 6-7-3-2 is hereby incorporated into the manual by reference.

f. After making the above notations, this memo shall be filed under Section 1 (Policy and Procedures).

In the past we have received numerous requests for copies of our Hydraulics Manual and previous Open-File Reports and we anticipate similar request for this report. If you feel that this Open-File Report will not be used by you or your staff, we request that you return it to the Hydraulics Unit.

Thank you for your cooperation.

Stephen C. Kologi

34:SCK:CSP:cg:6C

Attachment

DISTRIBUTION w/Attachment

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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

REVISED TECHNIQUES FOR ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS IN MONTANA

By Charles Parrett and R. J. Omang

U.S. GEOLOGICAL SURVEY

Open-File Report 81-917

Prepared in cooperation with the
MONTANA DEPARTMENT OF HIGHWAYS,
FEDERAL HIGHWAY ADMINISTRATION,
U.S. FOREST SERVICE, and the
U.S. BUREAU OF LAND MANAGEMENT

Helena, Montana
September 1981

UNITED STATES DEPARTMENT OF THE INTERIOR
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CONTENTS

ILLUSTRATIONS

TABLES

METRIC CONVERSION FACTORS

For those readers who may prefer to use the International System (SI) of metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below.

Multiply inch-pound unit	By	To obtain metric unit
cubic foot per second	0.02832	cubic meter per second
cubic foot per second per square mile	0.01093	cubic meter per second per square kilometer
foot	0.3048	meter
inch	25.40	millimeter
mile	1.609	kilometer
square mile	2.590	square kilometer

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by the equation:

$$°C = 0.556\ (°F - 32)$$

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level." NGVD of 1929 is referred to as sea level in this report.

REVISED TECHNIQUES FOR ESTIMATING MAGNITUDE AND FREQUENCY OF FLOODS IN MONTANA

By

Charles Parrett and R. J. Omang

ABSTRACT

Relations for estimating the flood magnitudes for ungaged sites in Montana have been updated. The State was divided into eight regions and separate multiple-regression equations for each region were developed that relate logarithms of annual flood magnitude to logarithms of basin characteristics for exceedance probabilities of 50, 20, 10, 4, 2, and 1 percent. The standard errors of estimate for an exceedance probability of 1 percent ranged from 39 to 58 percent in the western and central parts of the State and from 47 to 83 percent in the eastern part. The standard errors of estimate indicate a substantial improvement over previous studies. Techniques for transferring annual flood-frequency information at gaged sites to ungaged sites on the same stream have been updated. Included are curves relating flood-frequency information to drainage area for eight major streams in the State. Maximum known flood peaks in Montana are compared with estimated 1-percent-chance flood peaks and with national maximum known flood peaks.

Values of flood discharges for selected exceedance probabilities and values of significant basin characteristics for all gaging stations used in the analysis are tabulated. Included are data for 339 stations in Montana and 34 nearby stations in Canada and adjoining States.

INTRODUCTION

Reliable estimates of flood magnitude and frequency are essential for the economic design of hydraulic structures such as levees, bridges, and culverts. In addition, the recent increased emphasis on flood-plain land-use management and flood insurance has expanded the need for updated flood-frequency information. Although several previous studies (Berwick, 1958; Bodhaine and Thomas, 1964; Patterson, 1966; Boner and Omang, 1967; Boner and Buswell, 1970; Dodge, 1972; and Johnson and Omang, 1976) have provided techniques for estimating flood magnitude and frequency, streamflow-gaging records for small streams generally were not available.

The purpose of this report is to present updated techniques for estimating flood magnitude for exceedance probabilities of 50, 20, 10, 4, 2, and 1 percent for unregulated streams in Montana. The relations presented herein provide more reliable predictions than those in previous studies because of more extensive streamflow-gaging records and improved analytical procedures.

The report is based on gaging data from unregulated streams having at least 10 years of streamflow record. Included in the analysis are 339 streamflow-gaging

sites in Montana, 8 in Canada, 14 in North Dakota, 4 in South Dakota, and 8 in Wyoming. Locations and station numbers of all gages used in the analysis are shown in figure 1. Some streamflow-gaging sites having more than 10 years record were excluded from the analysis because the data were considered to be unreliable or unrepresentative of the region.

This report was prepared in cooperation with the Montana Department of Highways; the U.S. Department of Transportation, Federal Highway Administration; the U.S. Department of Agriculture, Forest Service; and the U.S. Department of the Interior, Bureau of Land Management.

GENERAL DESCRIPTION OF THE AREA

Montana, the fourth largest State, has widely varying geographic and climatic conditions. The western one-half is generally mountainous and forested with large intermontane valleys. The eastern one-half is generally flat or rolling prairie land with deeply incised larger streams.

The Rocky Mountains generally trend northward through the western one-third of the State, forming the Continental Divide. The northern parts of the divide are particularly steep and rugged. Smaller mountain ranges east and west of the divide are also prominent geographic features, and, in some instances, are as steep and rugged as the mountains along the divide.

The climate of the State is affected largely by the topography. Thus, in the western mountains, annual precipitation is significant and occurs mostly as snow. Most precipitation in western Montana originates in the Pacific Ocean. Peak runoff from mountain streams can result from either spring snowmelt or spring snowmelt mixed with rain. Along the east slope of the Continental Divide, severe flooding has resulted from rains produced from humid air masses originating in the Gulf of Mexico. Mountains along the west slope of the divide are generally protected from storms moving northward along the east slope. However, intense rainstorms sometimes cross the divide and cause severe flooding along the west slope (Boner and Stermitz, 1967, p. B16-B44).

In the eastern plains region, precipitation is more variable, more intense, and generally less, on an annual basis, than in the mountains. Runoff from the plains streams is also more variable than in the mountains and results from either snowmelt or rainfall. In some areas of the eastern plains, extreme flood peaks commonly are caused by intense summer thunderstorms. Although the entire eastern one-half of the State is probably susceptible to intense thunderstorms, the streamflow-gaging-station records collected thus far indicate that severe floods caused by thunderstorms occur in an area bounded approximately by the Missouri River on the north and the Yellowstone River on the south.

Because of the diverse topography and climate, the State was divided into eight regions for the flood-frequency analysis. The boundaries of the regions conform generally to the different physiographic areas described above and are illustrated in figure 1.

The West Region (fig. 1) includes the mountainous area west of the Continental Divide where annual precipitation is significant and runoff generally results from snowmelt. The Northwest Region includes the northern part of the Continental

Divide where severe floods are produced by intense rainfall from air masses originating in the Gulf of Mexico. The Southwest Region is also a mountainous region, but precipitation is generally less than in the West Region, and unit flood discharges, in cubic foot per second per square mile, are consequently smaller.

The Upper Yellowstone-Central Mountain Region is a mountainous, generally forested area similar to the West Region. Precipitation in this region also is significant, but generally more variable than in the West Region. Storms in the Upper Yellowstone-Central Mountain Region may originate from the north or south as well as from the west.

The Northwest-Foothills Region is an area of mostly rolling plains just east of the mountains of the Northwest Region. Unit flood discharges in this region tend to be larger than in similar plains areas farther east, apparently because the area is partly affected by intense rainfall that causes large floods in the Northwest Region.

The Northeast Plains Region is predominantly flat, plains land north of the Missouri River. Runoff is variable with most smaller streams flowing only intermittently. Floods are produced by snowmelt and rainfall.

The East-Central Plains Region is also predominantly flat plains but is the area most affected by intense summer thunderstorms. Thus, flood discharges tend to be even more variable than in the Northeast Plains Region, with annual unit flood discharges ranging from zero or near-zero to several hundred cubic feet per second per square mile of drainage area.

The Southeast Plains Region is similar in topography to both the Northeast Plains Region and the East-Central Plains Region. Flood peaks from intense thunderstorms are not as prevalent in the Southeast Plains Region as in the East-Central Plains Region. Annual precipitation is generally more variable and somewhat greater in the Southeast Plains Region than in the Northeast Plains. Unit flood discharges in the Southeast Plains Region thus tend to be higher and more variable than in the Northeast Plains, but not as variable or as high as in the East-Central Plains Region.

FLOOD-FREQUENCY ANALYSIS

In describing flood frequency in this report, the term "exceedance probability" is used rather than the term "recurrence interval." Both terms are used, however, in illustrative examples. Exceedance probability is the percentage chance that a flood will exceed a given magnitude in any 1 year. Recurrence interval is the reciprocal of the exceedance probability times 100 and is the average time interval, in years, between occurrences of a flood of equal or greater magnitude. For example, a 1-percent-chance flood has an exceedance probability of 1 percent and a recurrence interval of 100 years.

Flood magnitudes for selected exceedance probabilities were determined at each streamflow-gaging site by using a log-Pearson type III probability distribution to develop a flood-frequency curve. Techniques recommended by the U.S. Water Resources Council (1977) were used to fit the log-Pearson type III distribution to the annual peak discharges at each site. Historic adjustments to the recorded station data were used where applicable, and skew coefficients were taken from a regional map

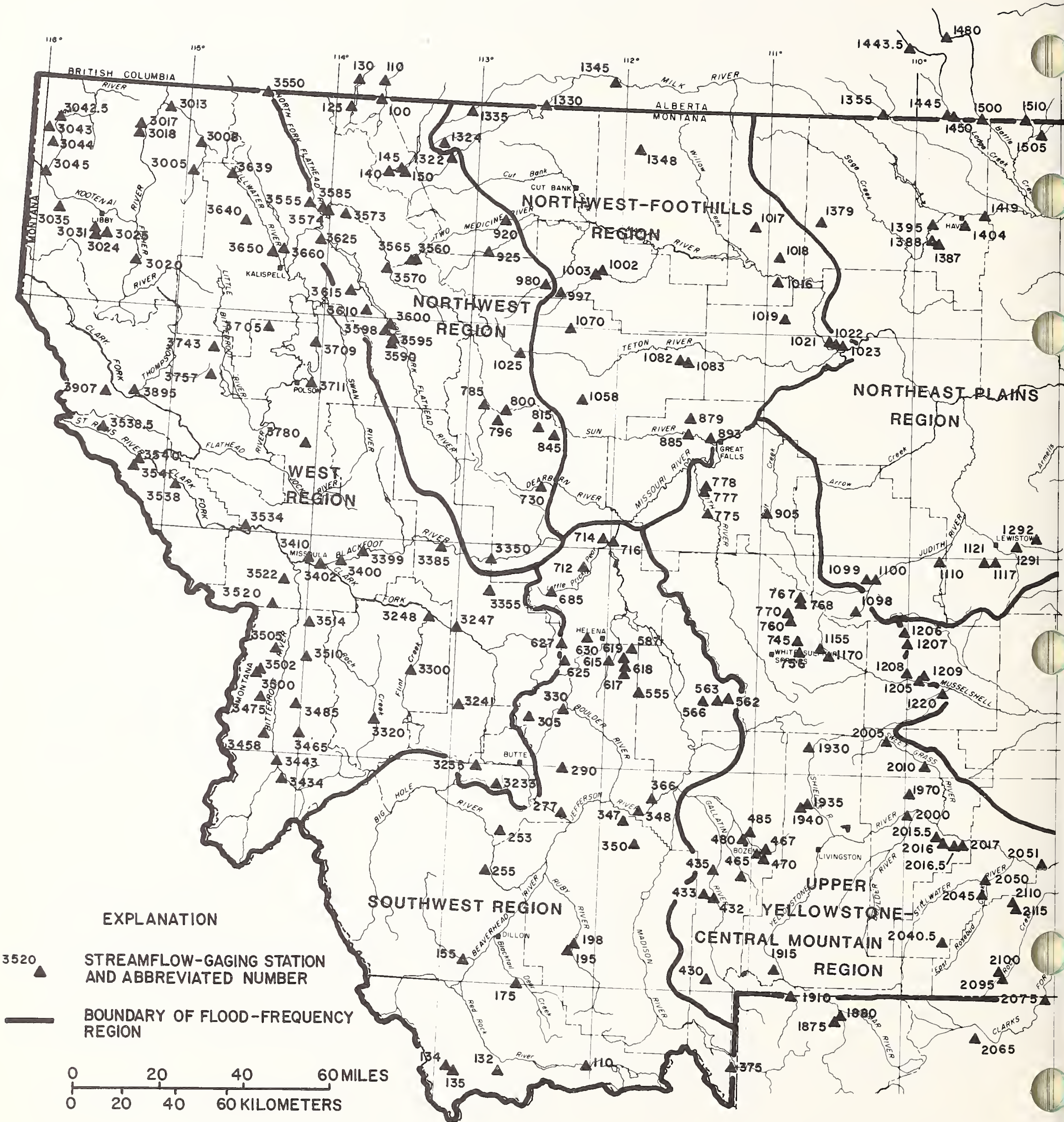
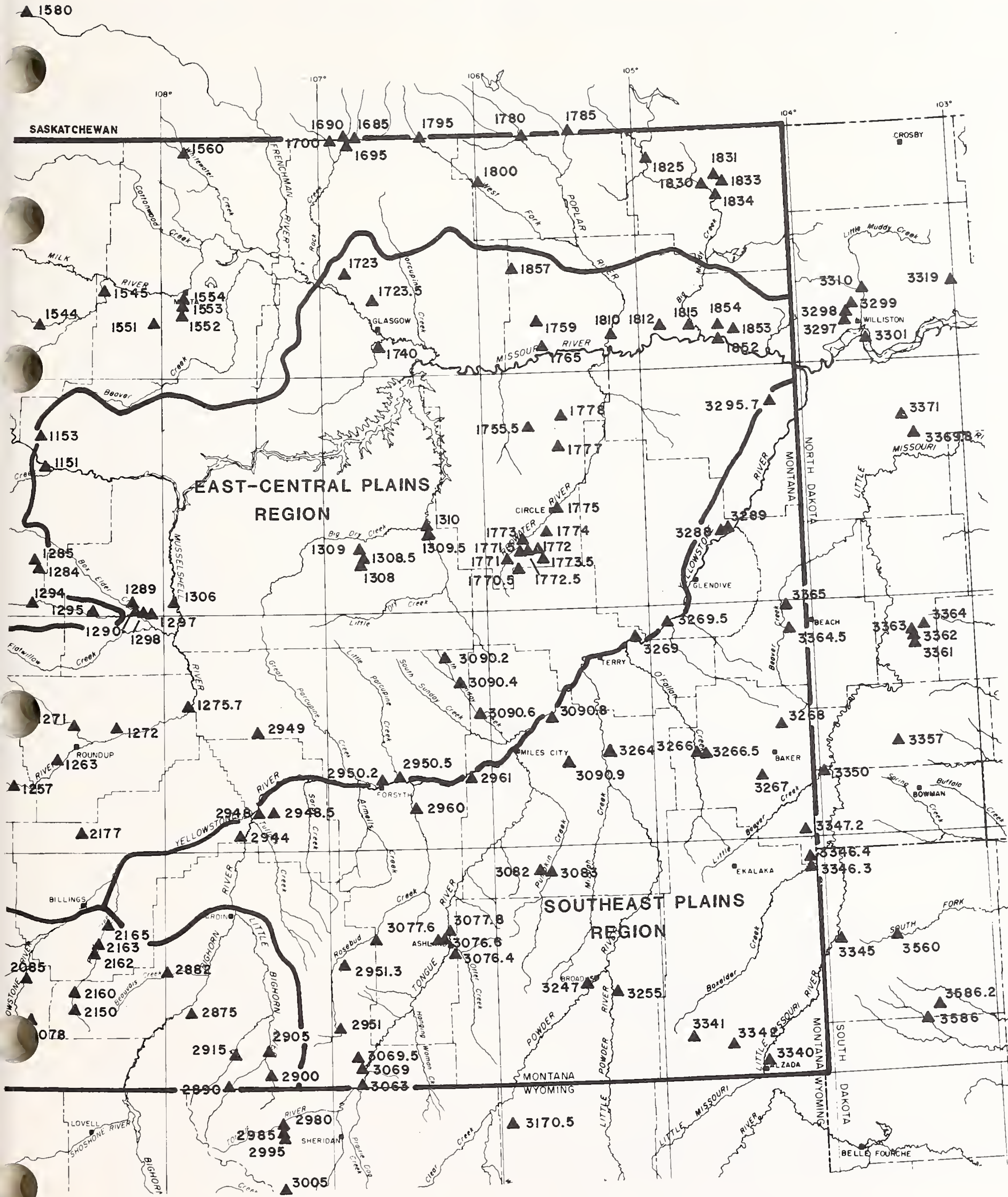


Figure 1.--Locations of selected streamflow-gaging stations



and boundaries of flood-frequency regions.

developed for this report. Flood-frequency data thus derived for each station used in the analysis are listed in table 1.

Although flood estimates are sometimes required for exceedance probabilities less than 1 percent, the reliability of such estimates is poor. Consequently, flood magnitudes greater than the 1-percent-chance flood were not used in the analysis.

Mixed-population analysis

In the Northwest Region, frequency-curve determination was complicated by a few extreme floods caused by rain within a population of smaller floods caused by snowmelt or snowmelt mixed with rain. Because the rain-caused floods are significantly larger than the more prevalent snowmelt-type floods, the log-Pearson type III distribution did not fit the data well when all floods were considered together. Accordingly, the peak discharges at each site in the region were separated by cause -- those caused by intense rains and those caused by snowmelt or snowmelt mixed with rain. Frequency curves were then fitted to each set of peak discharges, and the separate frequency curves were combined using procedures developed by the U.S. Army Corps of Engineers (1958). Fitting a frequency curve to the rain-caused flood peaks was complicated by the paucity of events. Rainfall-frequency curves were prepared for all long-term rain gages in the area and were used as a guide in assigning reasonable probabilities of occurrence to the few rain-caused flood peaks. Flood reports documenting the severity and rarity of the large rain-caused floods were also used to help assign probabilities of occurrence to rain-caused peaks (Boner and Stermitz, 1967; U.S. Army Corps of Engineers, 1969 and 1973). A sample frequency curve determined by this method is shown in figure 2.

Peak-flow records in the East-Central Plains Region also were examined to determine if thunderstorm-caused floods should be separated from snowmelt-caused floods. In this instance, the two types of flood peaks were not clearly distinct nor sufficiently independent, and separation was not warranted.

Regional skew

As recommended by the U.S. Water Resources Council (1977), generalized skew coefficients were used in the log-Pearson type III curve-fitting procedure. Because of the mixed-population frequency analysis made in the Northwest Region, generalized skew coefficients developed by the Water Resources Council were not applicable in that area. In addition, two large floods that occurred (1975 and 1978) after the completion of the Water Resources Council generalized skew map resulted in significantly larger station skew coefficients in the central and south-central parts of the State (Southwest and Upper Yellowstone-Central Mountain Regions). For example, 22 streamflow-gaging sites in the affected area have 35 or more years of record. Of these, 11 show a significant increase (0.10 or greater) in station skew coefficient when the additional record since the completion of the Water Resources Council skew map is considered. Only one site shows a significant decrease (0.10 or greater) in station skew as a result of the additional record, and 10 sites show no significant change in station skew. Consequently, a new generalized skew map for Montana was prepared (fig. 3). Skew coefficients for areas other than the Northwest, Southwest, and Upper Yellowstone-Central Mountain Regions are the same as shown on the U.S. Water Resources Council map.

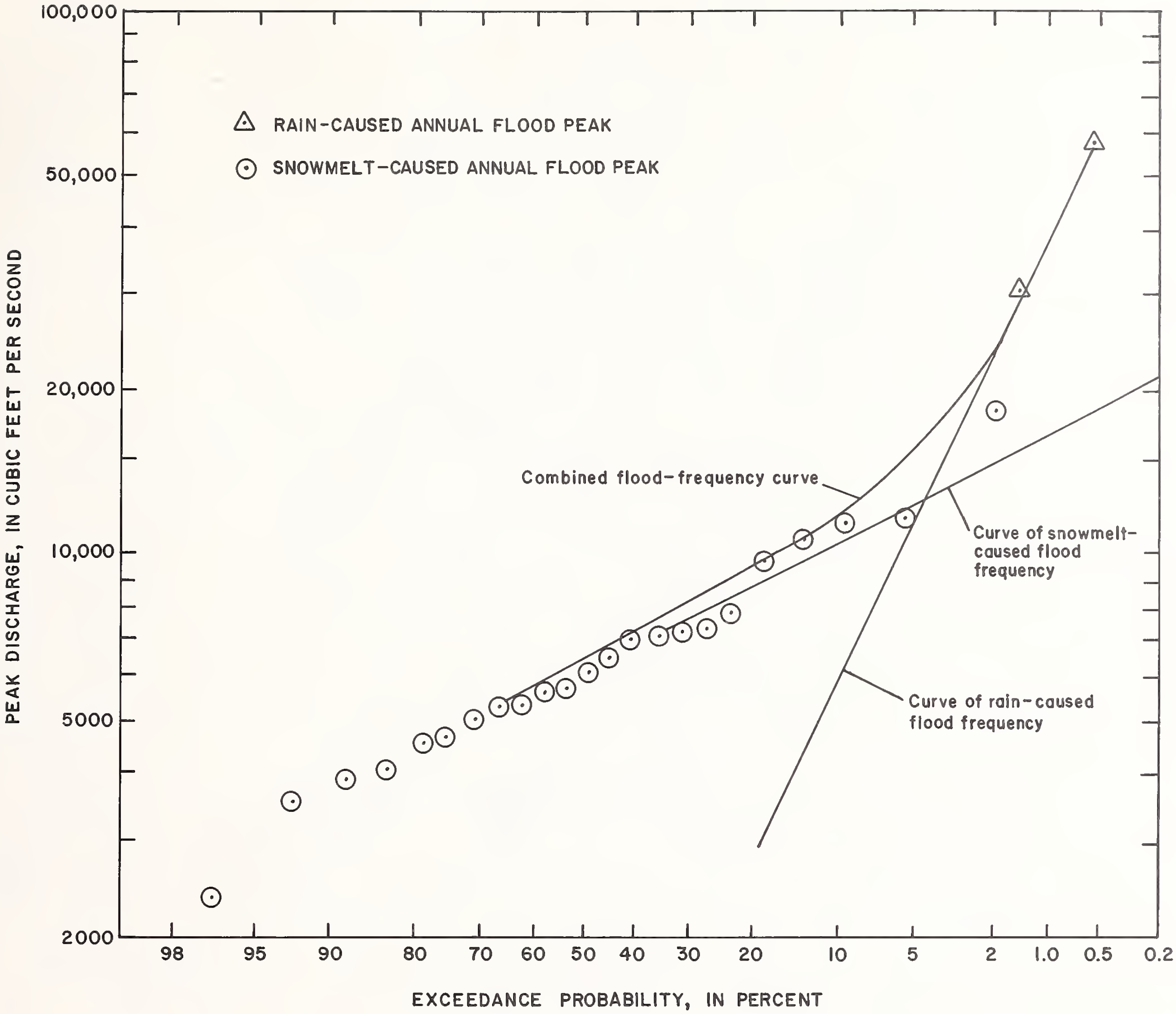


Figure 2.--Flood-frequency curve for Sun River near Augusta, Mont. (station 06080000).

REGIONAL FLOOD-FREQUENCY RELATIONS

Flood-frequency characteristics developed for streamflow-gaging stations were related to drainage-basin characteristics using multiple-regression techniques to define regional flood-frequency relations.

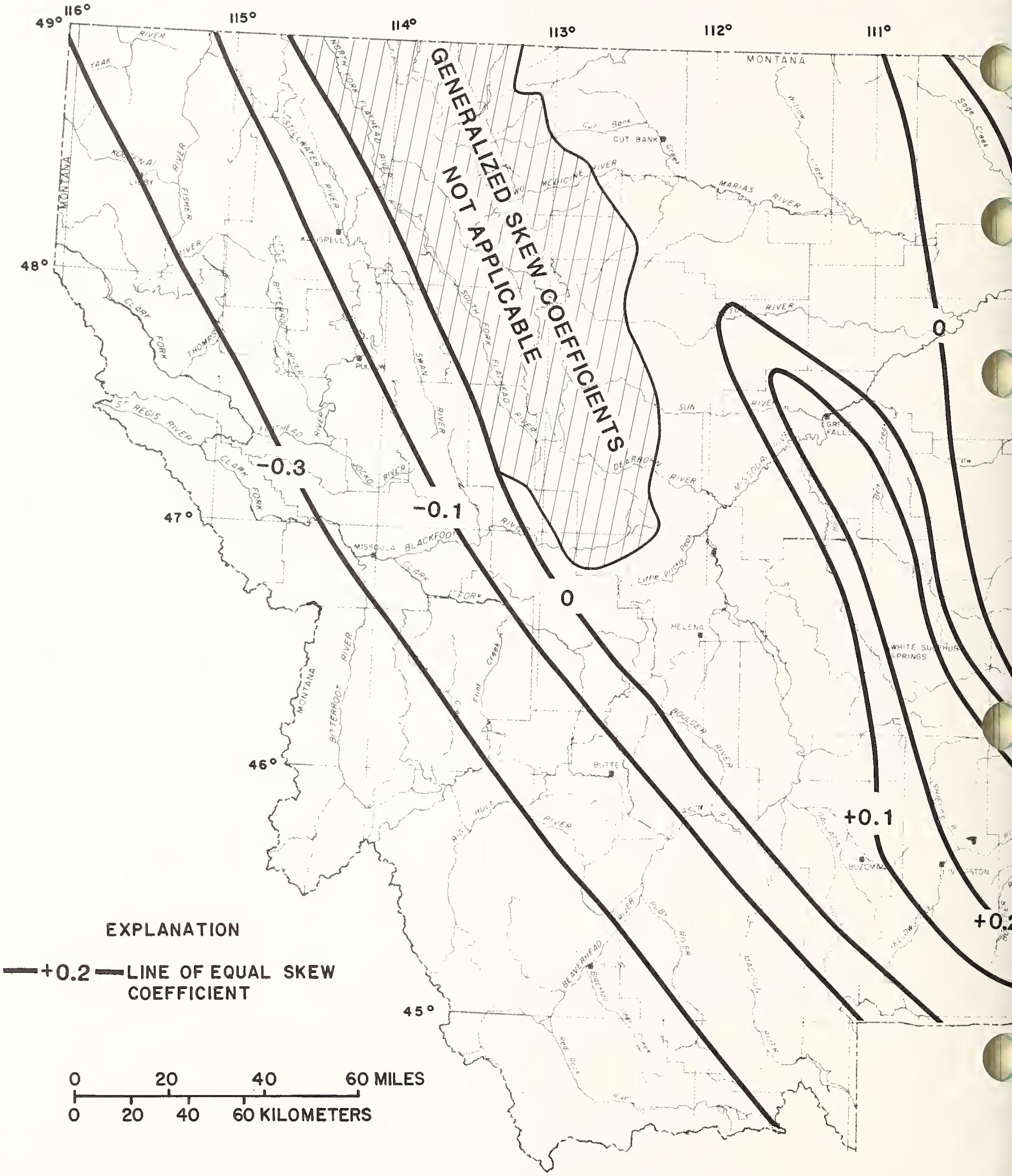
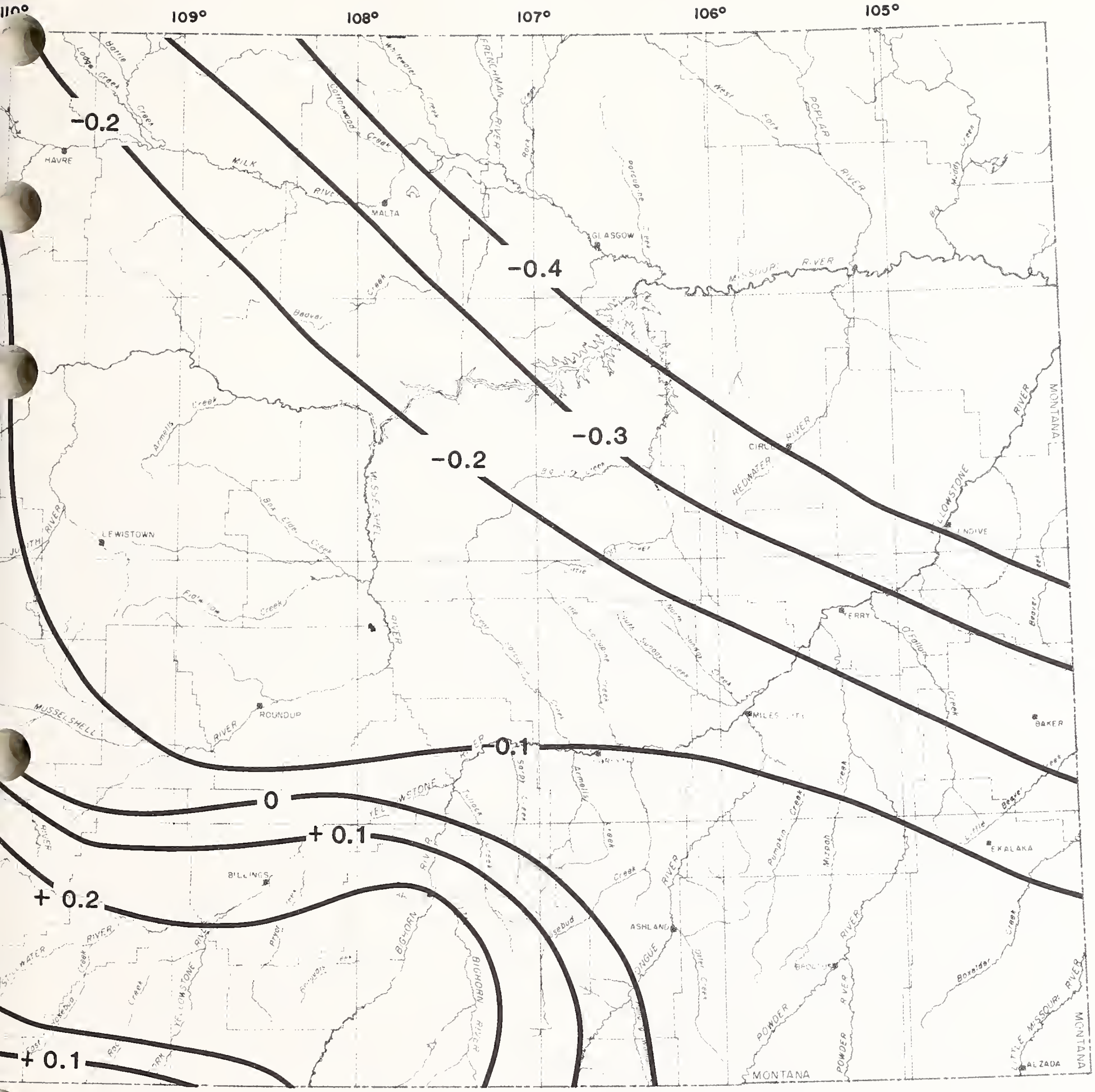


Figure 3.--Generalized skew



coefficients.

Basin characteristics used

Basin characteristics tested for inclusion as independent variables in the regression equations include:

A	drainage area,
P	mean annual precipitation,
F+10	forest cover index;
E/1000	mean basin elevation index;
HE+10	basin high-elevation index;
TI+10	temperature index;
LAT−44	site latitude index,
LNG−100	site longitude index,
S	main channel slope,
L	mean channel length,
*I*24	precipitation intensity for a storm of 24 hours duration having an exceedance probability of 50 percent, and
LAKE	percentage of basin covered by lakes and ponds.

Basin characteristics determined to be important in the regression equations were drainage area, mean annual precipitation, forest cover index, mean basin elevation index, basin high-elevation index, and temperature index. Drainage area is expressed in square miles, and is determined for ungaged sites by planimetering the area outlined on the largest scale topographic map available. Mean annual precipitation is the basin average, in inches, and can be determined from the average annual precipitation map (pl. 1). Forest cover index is the percentage of basin area covered by forest plus 10. The value 10 is added to the percentage of forest cover to ensure that a value of zero does not occur in the equations. The percentage of forest cover is determined by planimetering the forested areas shown on the best scale U.S. Geological Survey topographic maps, multiplying by 100, and dividing the result by the total basin drainage area.

Mean basin elevation index is the mean basin elevation, in feet above sea-level datum, divided by 1,000. Mean basin elevation can be determined by using a transparent grid overlay on a topographic map. The basin elevation at each grid intersection is determined, and the mean basin elevation is calculated by averaging. The basin high-elevation index is the percentage of the total basin area above 6,000 feet sea-level datum plus 10. Again, the value 10 is added to ensure that zero values do not occur in the equations. The percentage of basin area above 6,000 feet elevation can be determined by planimetering the drainage area above the 6,000-foot contour on a topographic map, multiplying by 100, and dividing the result by the total drainage area. The temperature index is the mean basin January minimum temperature, in degrees Fahrenheit plus 10. Values of *TI* for the Northeast Plains Region are shown in figure 4. Values of the basin characteristics used for each station are given in table 2.

Regression analysis

Mathematical equations expressing flood magnitude as a function of drainage-basin parameters were derived by multiple-regression techniques. A linear relationship between the logarithms of the variables was assumed so the general form of the mathematical model used is:

$$\text{Log } Q_t = \log K + a \log A + b \log B + \ldots + n \log N \tag{1}$$

or

$$Q_t = K A^a B^b \ldots N^n \tag{2}$$

where Q_t, the dependent variable, is a flood magnitude having exceedance probability t; K is a regression constant; A, B,. . . . N, the independent variables, are drainage-basin characteristics; and a, b,. . . .n are regression coefficients.

The multiple-regression analyses were performed using a computer program (SAS Institute, Inc., 1979) with a "maximum R^2 improvement" routine for adding or deleting independent variables (drainage-basin characteristics) to the model. R is the coefficient of correlation. This procedure determines the "best" one-variable model (largest R^2), the "best" two-variable model (greatest increase in R^2), and so forth until the specified maximum number of independent variables has been included. In this study, independent variables were examined, and the computer routine was run until six of the independent variables were included in the equations. The equations thus derived were examined, and, in all instances, the standard error of estimate for the best three-variable model was only slightly larger than for the best four-, five-, or six-variable model. In fact, in four regions the best two-variable model had a standard error of estimate as small as any of the models having more variables. Consequently, the final estimating equations were limited to a maximum of three independent variables.

An initial multiple-regression analysis was made for the entire State. The regression residuals (difference between the predicted Q_t from the regression equa-

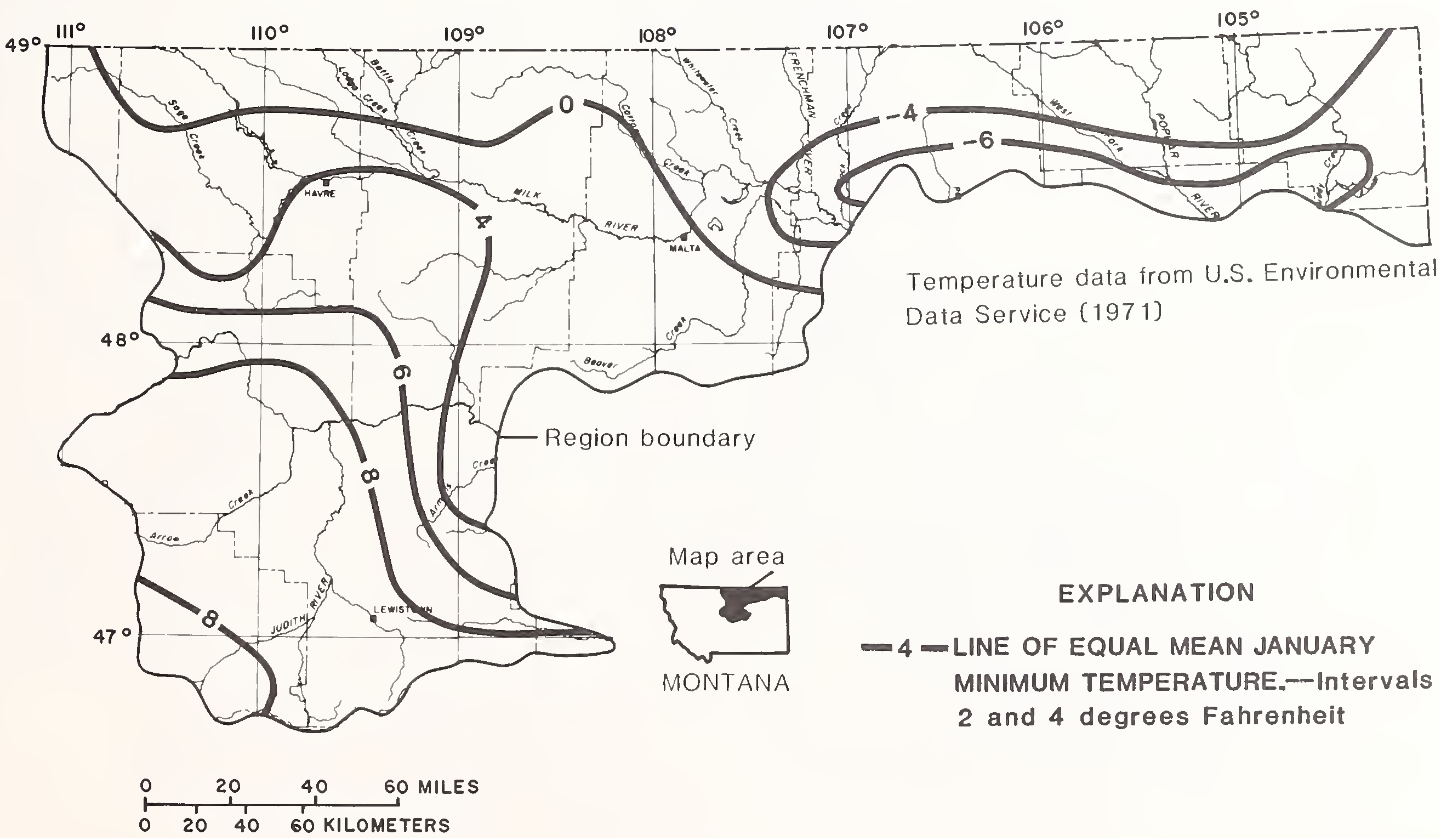


Figure 4.--Mean January minimum temperature (TI) for Northeast Plains Region.

tion and the Q_t determined from the station data-frequency curve) were plotted on a map and used, together with topographic maps, to delineate the eight regions finally used. Drainage divides were used as regional boundaries where feasible. Separate multiple-regression analyses were then made for each of the eight regions. A further refinement of the final equations was made by plotting antilogarithms of

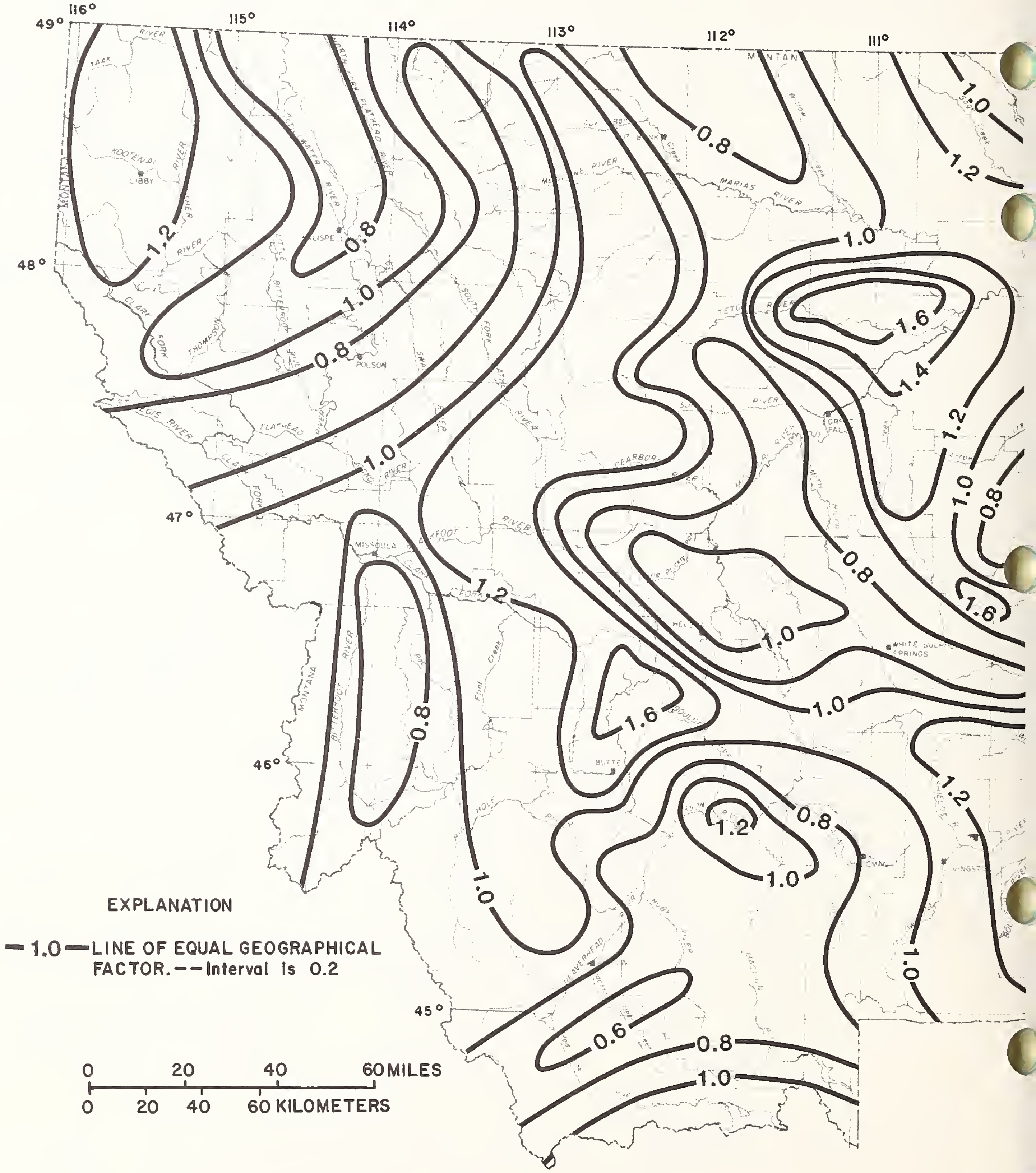
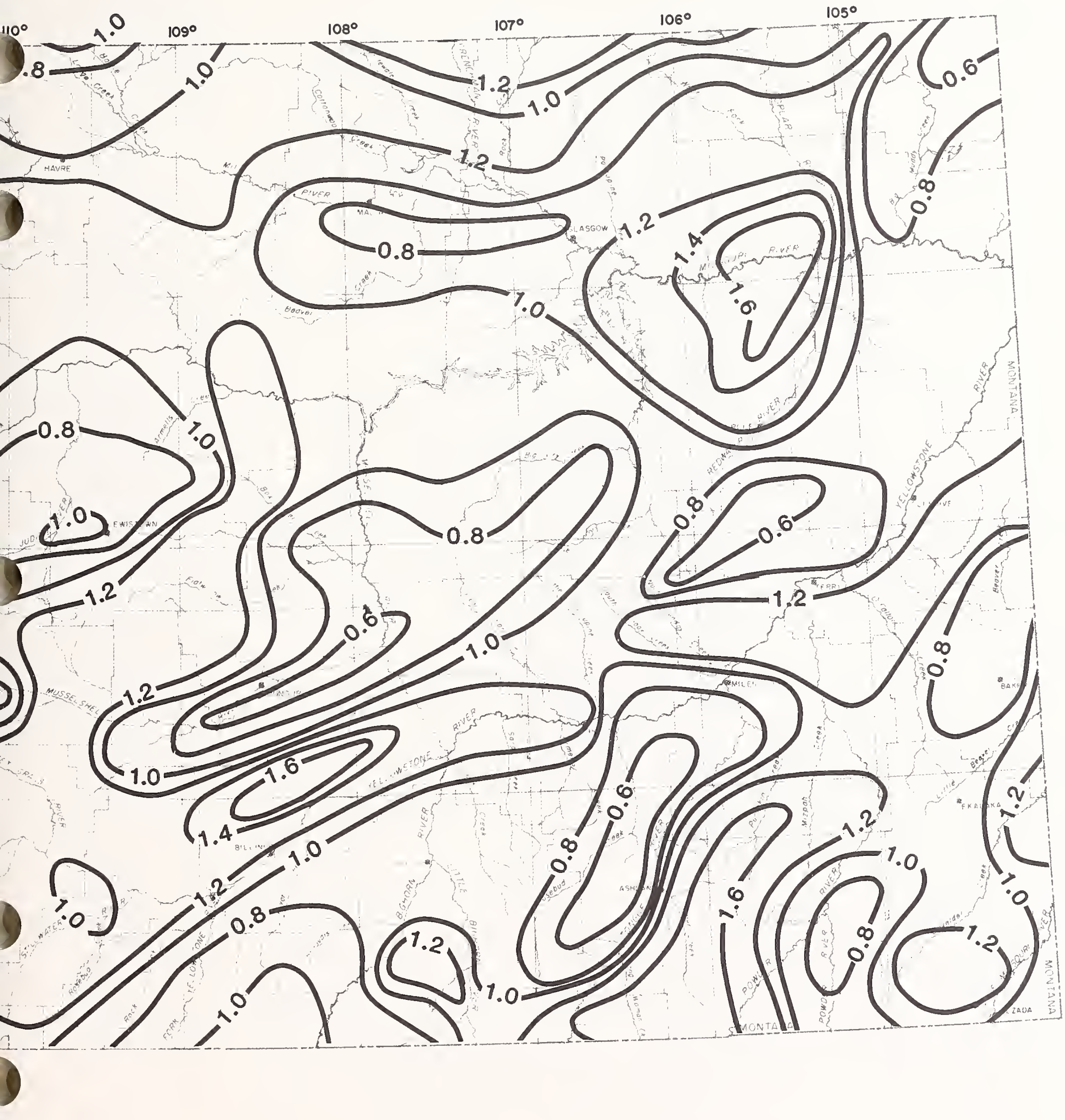


Figure 5.--Geographical

regression residuals for $Q_{1\%}$ on a State map and drawing lines through equal values. The lines thus drawn represent a geographical factor, G_f, that is used as a multiplier in the mathematical model. The geographical factor (fig. 5) may be considered as an additional basin characteristic that, for large drainage areas, may have to be determined by the grid-sampling method described earlier.



factors, G_f.

The final regression equations developed for each region and the standard errors of estimate with and without the geographical factor are given in table 3. The use of the geographical factor substantially improved the standard error of estimate for most exceedance probabilities in all regions.

Table 3.--*Regional flood-frequency equations*

Discharge (cubic feet per second for given exceedance probability)		Equations	Recurrence interval (years)	Standard error of estimate (percent) With G_f	Without G_f
West Region (57 stations)					
$Q_{50\%}$	=	$0.080\ A^{0.94}\ P^{1.29}\ G_f$	2	55	62
$Q_{20\%}$	=	$0.279\ A^{0.90}\ P^{1.11}\ G_f$	5	49	57
$Q_{10\%}$	=	$0.537\ A^{0.87}\ P^{1.02}\ G_f$	10	48	56
$Q_{4\%}$	=	$1.03\ A^{0.85}\ P^{0.93}\ G_f$	25	49	57
$Q_{2\%}$	=	$1.61\ A^{0.83}\ P^{0.86}\ G_f$	50	49	58
$Q_{1\%}$	=	$2.80\ A^{0.81}\ P^{0.77}\ G_f$	100	46	55
Northwest Region (34 stations)					
$Q_{50\%}$	=	$0.105\ A^{0.97}\ P^{1.33}\ G_f$	2	56	47
$Q_{20\%}$	=	$0.999\ A^{0.90}\ P^{0.93}\ G_f$	5	45	40
$Q_{10\%}$	=	$3.49\ A^{0.86}\ P^{0.72}\ G_f$	10	44	38
$Q_{4\%}$	=	$11.4\ A^{0.83}\ P^{0.54}\ G_f$	25	38	36
$Q_{2\%}$	=	$18.3\ A^{0.80}\ P^{0.54}\ G_f$	50	32	36
$Q_{1\%}$	=	$23.4\ A^{0.77}\ P^{0.61}\ G_f$	100	39	48
Southwest Region (36 stations)					
$Q_{50\%}$	=	$1.91\ A^{0.92}\ (HE+10)^{0.12}\ G_f$	2	58	73
$Q_{20\%}$	=	$22.3\ A^{0.85}\ (HE+10)^{-0.24}\ G_f$	5	45	56
$Q_{10\%}$	=	$78.6\ A^{0.82}\ (HE+10)^{-0.43}\ G_f$	10	42	56
$Q_{4\%}$	=	$328\ A^{0.77}\ (HE+10)^{-0.65}\ G_f$	25	45	62
$Q_{2\%}$	=	$815\ A^{0.74}\ (HE+10)^{-0.79}\ G_f$	50	51	70
$Q_{1\%}$	=	$1{,}890\ A^{0.72}\ (HE+10)^{-0.92}\ G_f$	100	58	78
Upper Yellowstone-Central Mountain Region (71 stations)					
$Q_{50\%}$	=	$0.146\ A^{0.87}\ (E/1000)^{3.88}\ (HE+10)^{-0.78}\ G_f$	2	57	60
$Q_{20\%}$	=	$1.08\ A^{0.82}\ (E/1000)^{3.56}\ (HE+10)^{-0.93}\ G_f$	5	47	51
$Q_{10\%}$	=	$3.22\ A^{0.80}\ (E/1000)^{3.39}\ (HE+10)^{-1.02}\ G_f$	10	45	49
$Q_{4\%}$	=	$10.6\ A^{0.77}\ (E/1000)^{3.20}\ (HE+10)^{-1.12}\ G_f$	25	42	48
$Q_{2\%}$	=	$23.6\ A^{0.75}\ (E/1000)^{3.06}\ (HE+10)^{-1.18}\ G_f$	50	43	48
$Q_{1\%}$	=	$48.8\ A^{0.73}\ (E/1000)^{2.95}\ (HE+10)^{-1.24}\ G_f$	100	44	49

Table 3.--*Regional flood-frequency equations*--Continued

Discharge (cubic feet per second for given exceedance probability)	Equations	Recurrence interval (years)	Standard error of estimate (percent) With G_f	Standard error of estimate (percent) Without G_f
Northwest-Foothills Region (21 stations)				
$Q_{50\%}$	$= 0.342\ A^{0.52}\ (E/1000)^{2.96}\ G_f$	2	105	101
$Q_{20\%}$	$= 1.65\ A^{0.47}\ (E/1000)^{2.76}\ G_f$	5	64	61
$Q_{10\%}$	$= 3.87\ A^{0.45}\ (E/1000)^{2.63}\ G_f$	10	48	51
$Q_{4\%}$	$= 9.68\ A^{0.43}\ (E/1000)^{2.48}\ G_f$	25	42	48
$Q_{2\%}$	$= 17.7\ A^{0.42}\ (E/1000)^{2.37}\ G_f$	50	44	60
$Q_{1\%}$	$= 30.7\ A^{0.40}\ (E/1000)^{2.27}\ G_f$	100	50	70
Northeast Plains Region (51 stations)				
$Q_{50\%}$	$= 26.3\ A^{0.65}\ (E/1000)^{0.53}\ (TI+10)^{-0.62}\ G_f$	2	61	61
$Q_{20\%}$	$= 114\ A^{0.61}\ (E/1000)^{0.09}\ (TI+10)^{-0.52}\ G_f$	5	43	46
$Q_{10\%}$	$= 214\ A^{0.59}\ (E/1000)^{-0.11}\ (TI+10)^{-0.44}\ G_f$	10	39	45
$Q_{4\%}$	$= 377\ A^{0.56}\ (E/1000)^{-0.28}\ (TI+10)^{-0.33}\ G_f$	25	40	49
$Q_{2\%}$	$= 519\ A^{0.55}\ (E/1000)^{-0.38}\ (TI+10)^{-0.26}\ G_f$	50	43	53
$Q_{1\%}$	$= 667\ A^{0.53}\ (E/1000)^{-0.46}\ (TI+10)^{-0.18}\ G_f$	100	47	59
East-Central Plains Region (54 stations)				
$Q_{50\%}$	$= 117\ A^{0.56}\ (E/1000)^{-1.50}\ G_f$	2	77	85
$Q_{20\%}$	$= 402\ A^{0.52}\ (E/1000)^{-1.42}\ G_f$	5	58	72
$Q_{10\%}$	$= 681\ A^{0.50}\ (E/1000)^{-1.31}\ G_f$	10	58	77
$Q_{4\%}$	$= 1{,}100\ A^{0.48}\ (E/1000)^{-1.13}\ G_f$	25	66	87
$Q_{2\%}$	$= 1{,}460\ A^{0.47}\ (E/1000)^{-0.99}\ G_f$	50	74	102
$Q_{1\%}$	$= 1{,}750\ A^{0.45}\ (E/1000)^{-0.82}\ G_f$	100	83	106
Southeast Plains Region (49 stations)				
$Q_{50\%}$	$= 360\ A^{0.59}\ (F+10)^{-0.98}\ G_f$	2	105	116
$Q_{20\%}$	$= 1{,}010\ A^{0.58}\ (F+10)^{-0.99}\ G_f$	5	77	90
$Q_{10\%}$	$= 1{,}320\ A^{0.56}\ (F+10)^{-0.91}\ G_f$	10	72	88
$Q_{4\%}$	$= 1{,}890\ A^{0.54}\ (F+10)^{-0.85}\ G_f$	25	68	87
$Q_{2\%}$	$= 2{,}340\ A^{0.54}\ (F+10)^{-0.81}\ G_f$	50	69	88
$Q_{1\%}$	$= 2{,}770\ A^{0.53}\ (F+10)^{-0.76}\ G_f$	100	71	91

Limitations of regression equations

The regression equations provide a means for determining flood peaks for selected exceedance probabilities for ungaged streams in Montana. The equations were developed from gaging-station data on virtually unregulated streams where significant urbanization or other major basin changes have not occurred. Thus, the equations may not be valid where regulation is a factor or where a drainage basin has been altered by urbanization.

The regression equations also will not be valid where unique, localized geologic features affect floods. Such areas would include those where a substantial part of the streamflow results from springs or seeps and areas where soils are so permeable that unusual amounts of runoff are absorbed.

The regression equations are also not generally usable for determining $Q_{2\%}$ and $Q_{1\%}$ in the Northwest-Foothills Region for any stream that originates in the Northwest Region. Streams that originate in the Northwest Region have a large $Q_{2\%}$ and $Q_{1\%}$ as a result of intense rains from southern sources. As these streams drain from the mountains and enter the relatively flat plains area of the Northwest-Foothills Region, the high flows are largely attenuated by valley storage. Thus, the peak discharges at downstream points commonly are the same as or less than the peak discharges at upstream locations. The $Q_{2\%}$ and $Q_{1\%}$ contribution from the Northwest Region can be calculated by using basin characteristics at the region boundary, but determining whether $Q_{2\%}$ and $Q_{1\%}$ increase, stay constant, or decrease with increasing downstream drainage area requires careful, individual study of the stream in question.

Flood discharges for streams that cross other regional boundaries can be determined by a weighting procedure as discussed in the "Weighting of Independent Estimates" section of this report. The procedure also applies to determining flood discharges for exceedance probabilities other than 2 percent and 1 percent for streams that drain from the Northwest to the Northwest-Foothills Regions.

As with any regression analysis, the derived equations are defined only within the range of the independent variables used. For this study, the range of values of the basin charateristics used is listed in table 4. Extrapolation beyond the range of values given in table 4 is not recommended.

The indiscriminate use of regression equations is no substitute for sound hydrologic judgment. The designer or hydrologist responsible for making flood estimates needs to be aware of situations where the regression equations may, perhaps inexplicably, provide unreliable results. In these instances, additional study, including perhaps onsite visits and conversations with long-time residents, is needed to decide between alternative estimating techniques and to determine when an estimate is sufficiently accurate.

Accuracy appraisal

The accuracy of a multiple-regression equation is most commonly measured by the standard error of estimate (SE_R). The standard error of estimate is the standard deviation of the distribution (assumed normal) of residuals about the regression line and is usually expressed in percentage of the estimated value when log-transformed variables are used. Thus, if the standard error of estimate of a

regression equation is 50 percent, about two-thirds of all observed values of the dependent variable will be within 50 percent of the estimated values.

The standard error of estimate for each regression equation is given in table 3. The largest standard errors occur generally in the East-Central Plains and the Southeast Plains Regions. Conversely, the smallest standard errors occur in the Northwest Region. In all regions, except the Southwest and East-Central Plains Regions, the largest standard error occurs in the $Q_{50\%}$ prediction equation. In the Southwest and East-Central Plains Regions, the largest standard errors occur in the $Q_{1\%}$ prediction equation.

The standard errors of estimate in table 3 represent a substantial improvement over results in previous studies. Johnson and Omang (1976), for example, show a standard error of estimate for the $Q_{50\%}$ equation ranging from 66 to 150 percent and a standard error of estimate for the $Q_{1\%}$ equation ranging from 70 to 106 percent. Boner and Buswell (1970) likewise reported a standard error of estimate for a $Q_{4\%}$ prediction equation ranging from 37 to 91 percent.

Table 4.--*Range of basin characteristics used*

Region	Drainage area (*A*) (square miles)	Mean annual precip- itation (*P*) (inches)	Forest cover (*F*) (percent)	Mean basin elevation (*E*) (feet)	Basin above 6,000 feet elevation (*HE*) (percent)	Mean minimum January temper- ature (*TI*) (degrees Fahrenheit)
West	0.86-2,290	12-79	--	--	--	--
Northwest	0.14-1,660	15-105	--	--	--	--
Southwest	0.48-2,480	--	--	--	0-100	--
Upper Yellow- stone-Central Mountain	1.44-2,620	--	--	3,780-9,560	0-100	--
Northwest- Foothills	0.25-1,040	--	--	2,750-5,130	--	--
Northeast Plains	0.11-1,810	--	--	2,110-6,540	--	(-5)-(+10)
East-Central Plains	0.22-3,170	--	--	2,090-5,400	--	--
Southeast Plains	0.04-1,970	--	0-64	--	--	--

Maximum known floods

Floods of record and the corresponding drainage areas for each gaging station within each region are displayed in figures 6-13. Also shown in these figures are curves relating the maximum known floods in the United States to drainage areas and curves relating the 1-percent-chance flood peaks to drainage areas. The 1-percent-chance flood relation was determined from regression equations using drain-

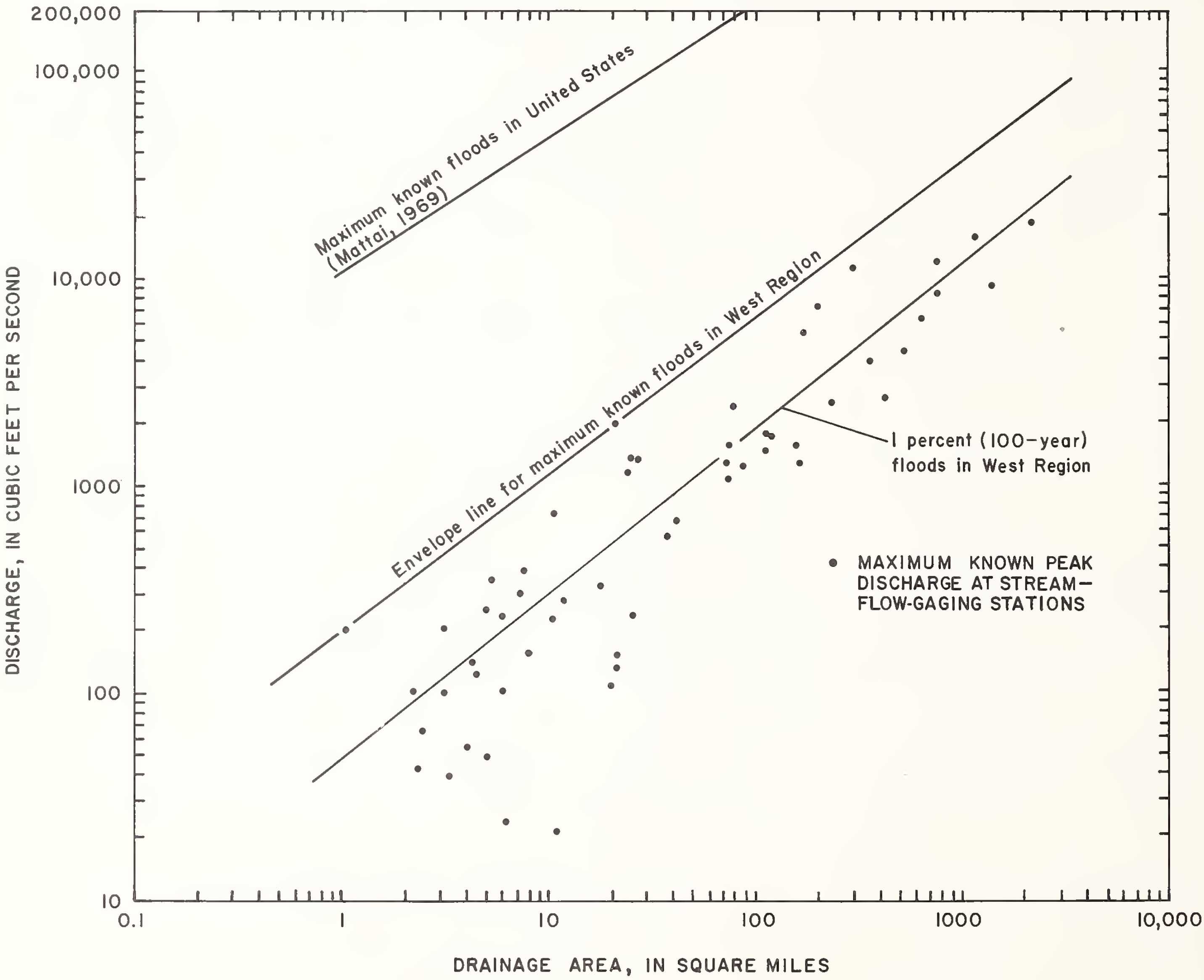


Figure 6.--Relation of maximum known peak discharge to drainage area in the West Region.

age area as the only independent variable. The data in figures 6 through 13 provide a comparison of Montana flood experience with the national flood experience. For example, the envelope line for the maximum known floods in the Northwest Region is near the national maximum relation in figure 7. The illustration also shows that the maximum known floods for most of the streamflow-gaging stations in the region are substantially above the 1-percent-chance flood relation, indicating that the Northwest Region has been subjected to occasional extreme floods.

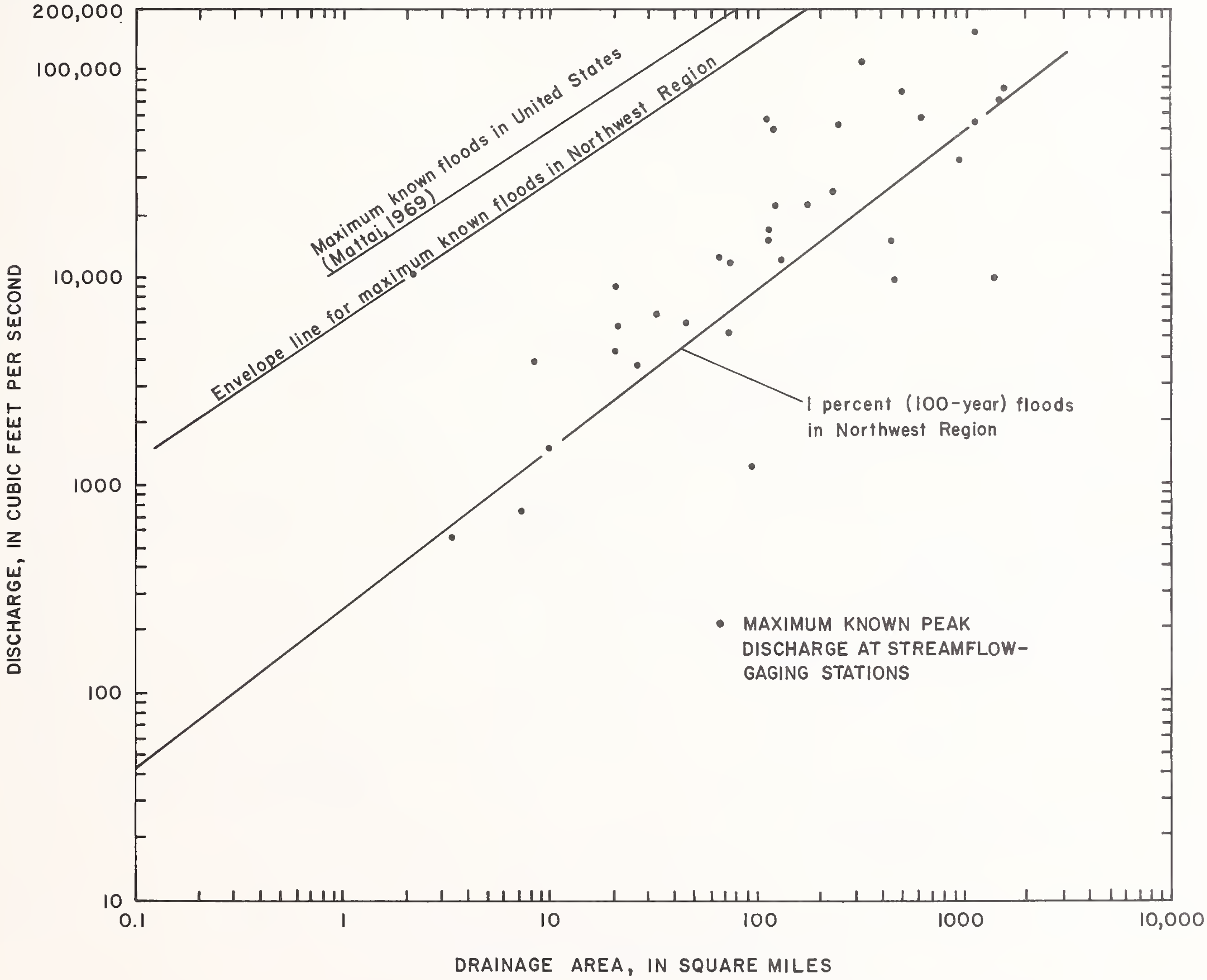


Figure 7.--Relation of maximum known peak discharge to drainage area in the Northwest Region.

WEIGHTING OF INDEPENDENT ESTIMATES

The U.S. Water Resources Council (1977, p. 8-1) has suggested that flood-frequency characteristics at gaged sites could be estimated better by weighting the station characteristics with characteristics defined by regional (regression) equations. The Water Resources Council further suggests that the weight given to each estimate should be inversely proportional to its variance.

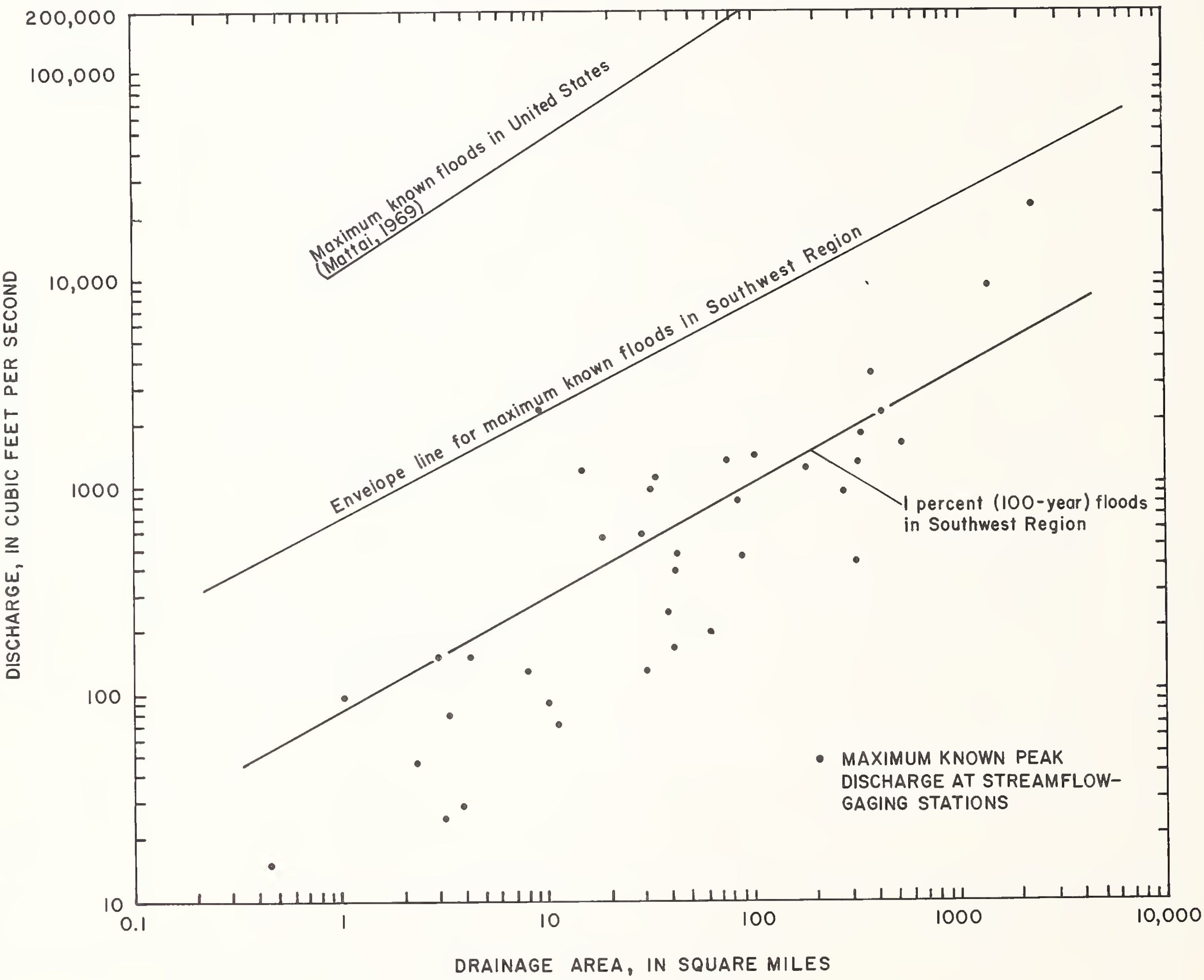


Figure 8.--Relation of maximum known peak discharge to drainage area in the Southwest Region.

The variance of a regional flood-frequency estimate is the square of the standard error of estimate, $(SE_R)^2$. Hardison (1971) has proposed that the average variance of a station flood frequency estimate, $\overline{V}_T$, be defined as:

$$\overline{V}_T = \frac{R^2(\overline{I}_V)^2}{N} \tag{3}$$

where R is a function of the average regional skew and the exceedance probability, $\overline{I}_V$ is the regional average standard deviation of the logs of the annual peak flows, and N is the length of record at the station.

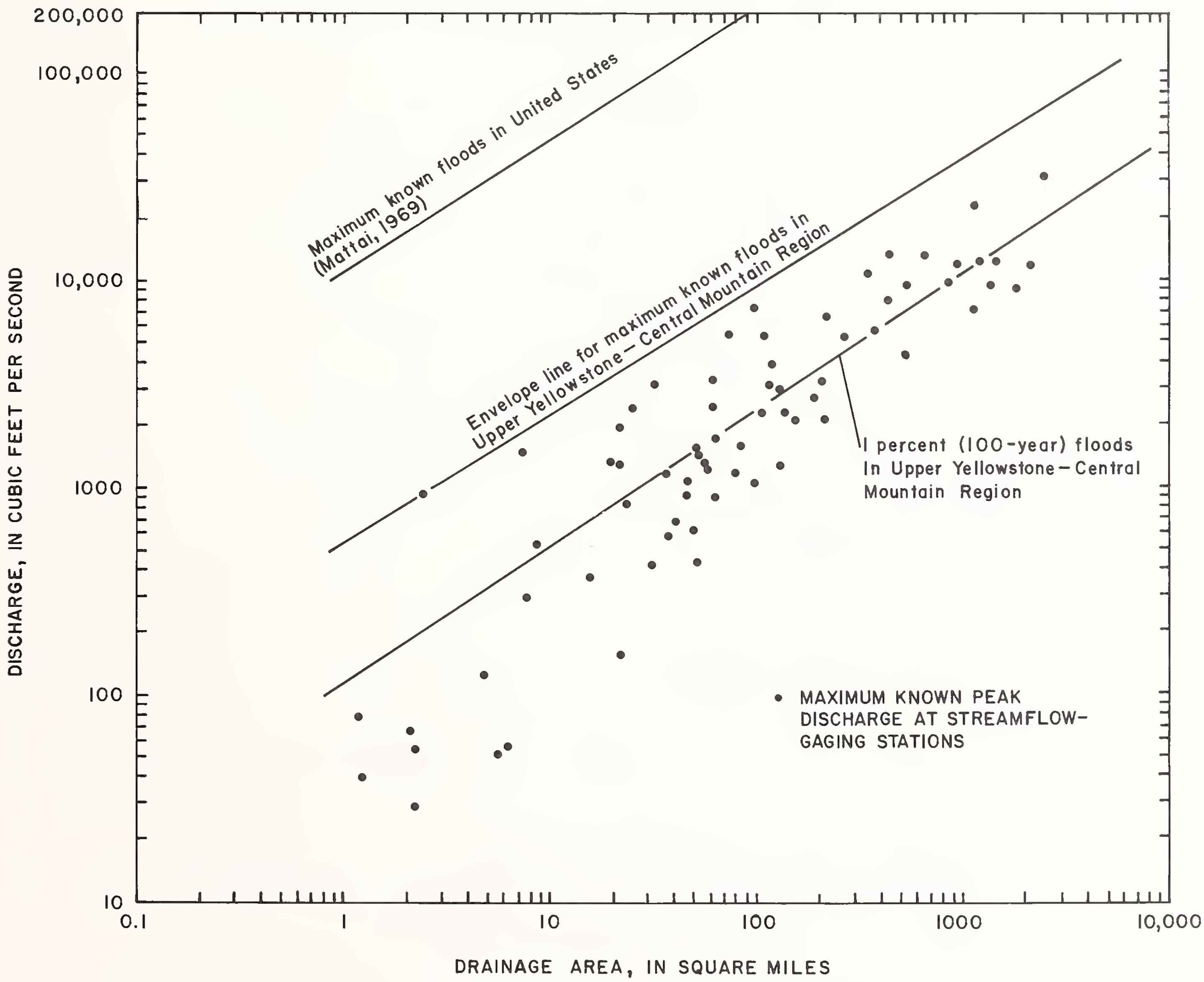


Figure 9.--Relation of maximum known peak discharge to drainage area in the Upper Yellowstone-Central Mountain Region.

Assuming independence of the two estimates, the final weighted value of the flood-frequency characteristic, Q_W, is then determined as:

$$Q_W = \frac{Q_R \overline{V}_T + Q_S \, (SE_R)^2}{\overline{V}_T + (SE_R)^2}, \tag{4}$$

where Q_R is the flood-frequency characteristic obtained from the regional equation, and Q_S is the flood-frequency characteristic obtained from the station data.

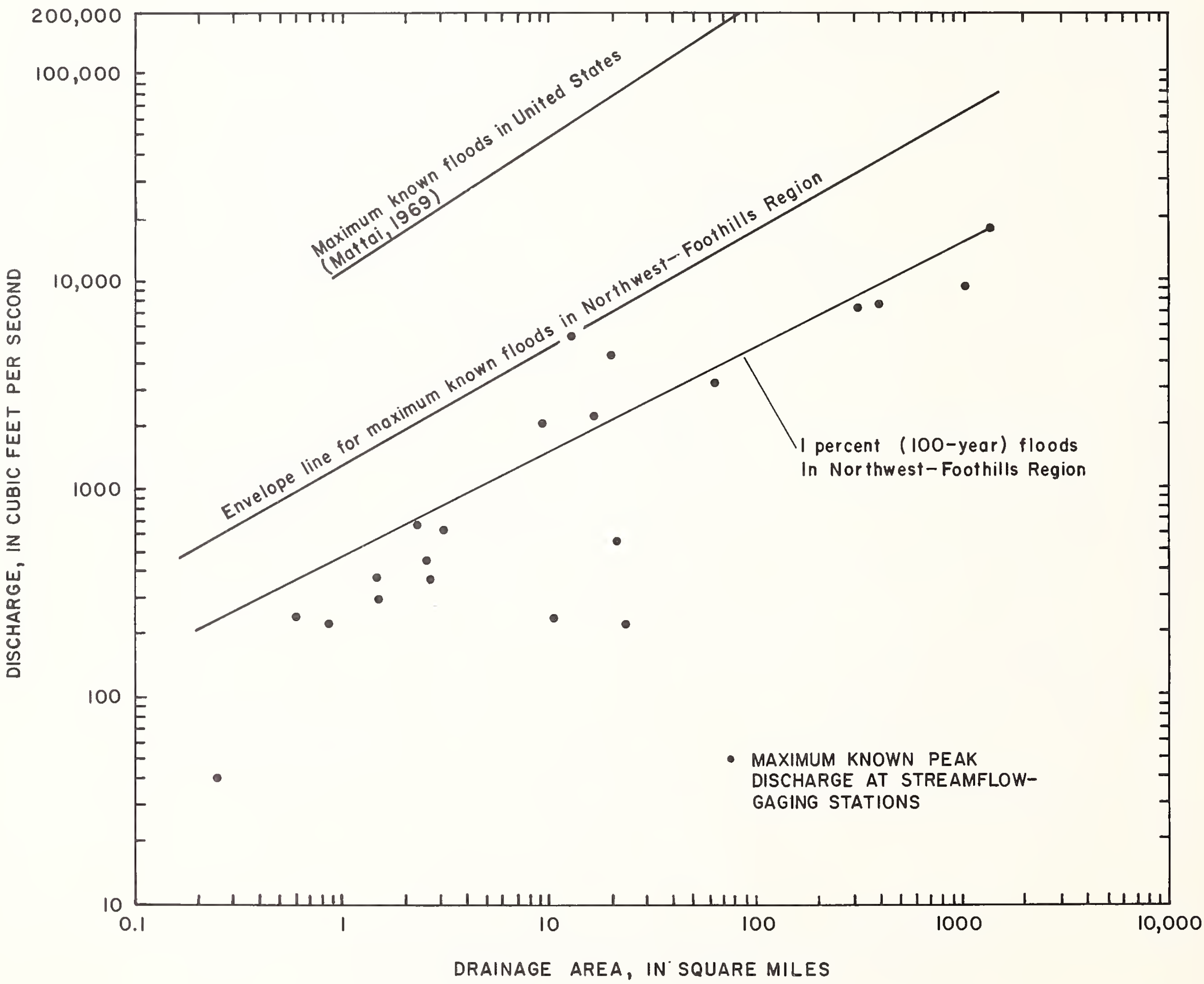


Figure 10.--Relation of maximum known peak discharge to drainage area in the Northwest-Foothills Region.

As indicated by equation 4, more weight is given to the station data when the standard error of estimate is large. Also, because $\overline{V_T}$ is inversely proportional to the record length, N, more weight is given to the station data as the record length increases.

Weighted values of the flood magnitude for exceedance probabilities of 1, 2, 4, 10, 20, and 50 percent were computed for all stations used in the regression analyses and are given with the station values and the regional estimates in table 1. The weighted values are considered to be the best available estimates at the gaged sites.

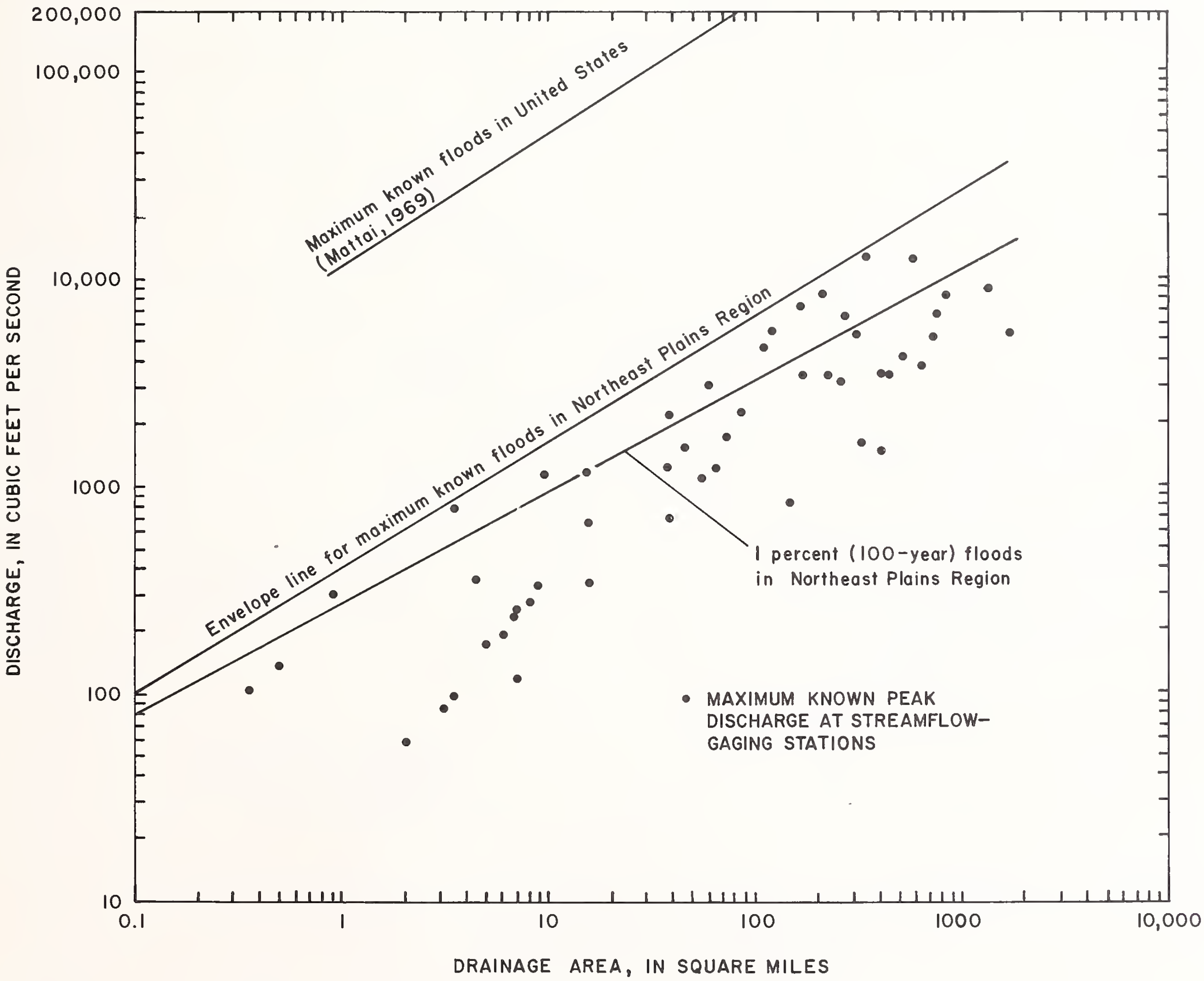


Figure 11.--Relation of maximum known peak discharge to drainage area in the Northeast Plains Region.

If an estimate of a flood-frequency characteristic is required at a site a short distance upstream or downstream from a gaged site, the weighted value of the characteristic at the gaged site can usually be transferred with good reliability. This transfer technique is based on the drainage-area ratio of the ungaged site to the gaged site as follows:

$$Q_t = (A_u/A_g)^a \, Q_{w,t} \tag{5}$$

where Q_t is the flood magnitude being estimated with exceedance probability t,

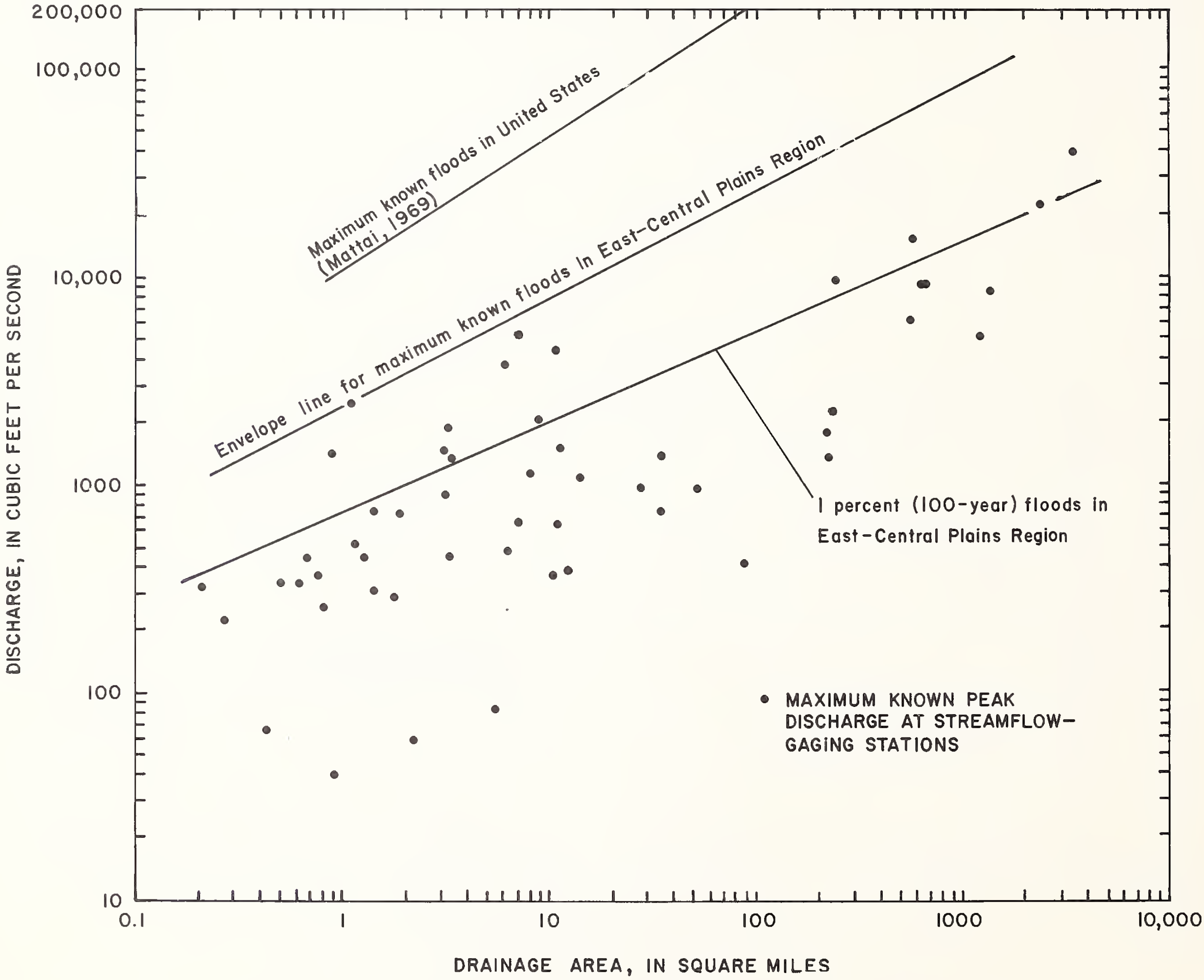


Figure 12.--Relation of maximum known peak discharge to drainage area in the East-Central Plains Region.

A_u is the drainage area at the ungaged site, A_g is the drainage area at the gaged site, a is the exponent of drainage area for the appropriate region and desired exceedance probability as given in table 3, and $Q_{w,t}$ is the weighted value of the station flood magnitude with exceedance probability obtained from table 1. This transfer technique is reliable only when the ungaged drainage area does not differ from the gaged drainage area by more than about 50 percent. Also, the transfer relation will be unreliable if used to predict $Q_{1\%}$ and $Q_{2\%}$ for streams where the ungaged site is in the Northwest-Foothills Region and the gaged site is in the Northwest Region.

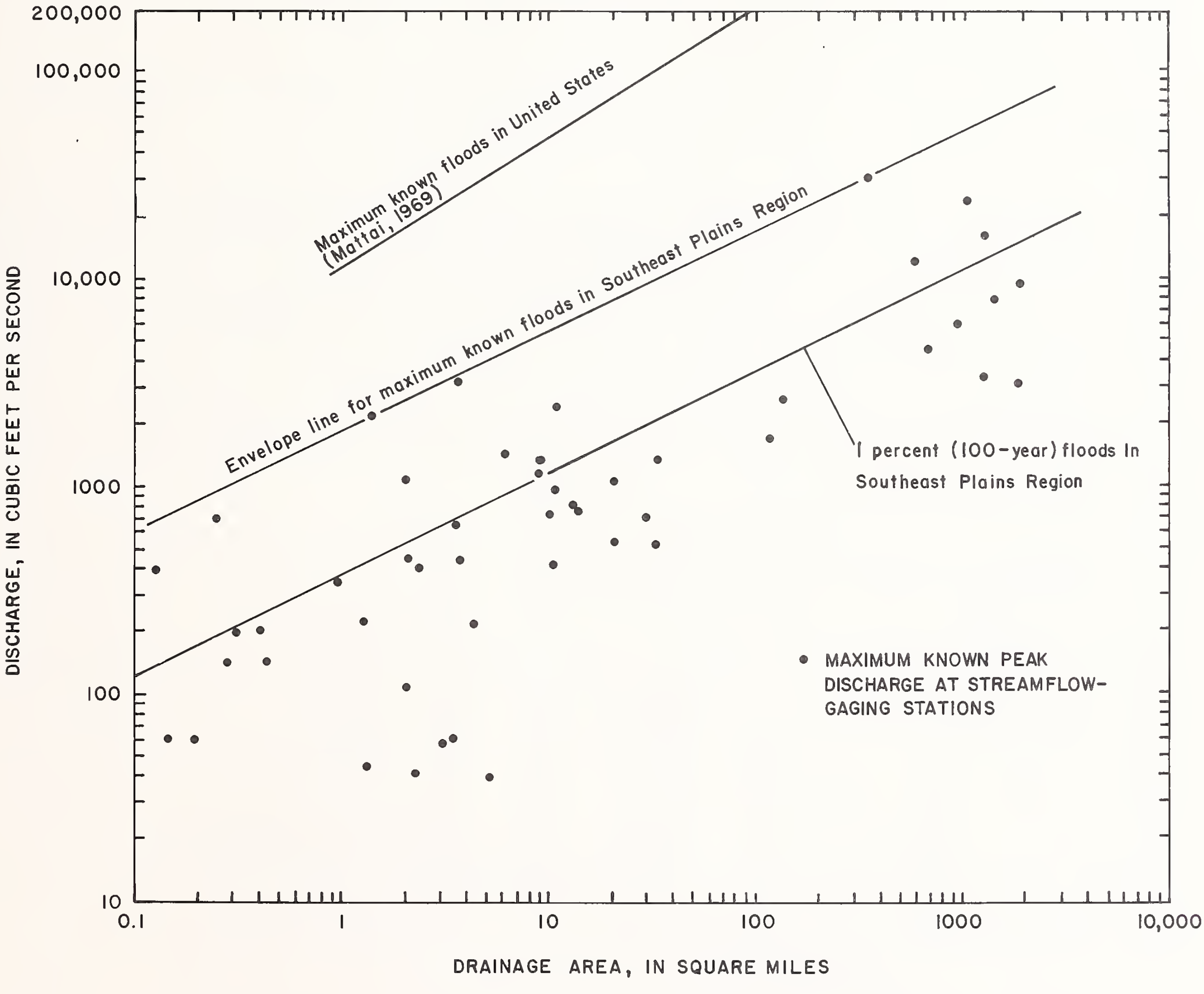


Figure 13.--Relation of maximum known peak discharge to drainage area in the Southeast Plains Region.

On large streams having several gaged sites or sites where flood-magnitude estimates have been made for National Flood Insurance Studies, flood magnitudes between the sites can be interpolated from curves relating flood magnitude to drainage-area size. Relationships of flood magnitude to drainage area for all major streams in Montana where interpolation was considered to be applicable are presented in figures 14-21. For ungaged sites with drainages smaller than those shown in figures 14-21, the appropriate regression equation should be used to estimate flood magnitude. Diversions and regulation that occur between some sites may significantly affect $Q_{50\%}$. For example, on the Milk (fig. 16) and Musselshell (fig. 18) Rivers, $Q_{50\%}$ decreases between two sites having increasing drainage area. $Q_{1\%}$ also decreases between two sites having increasing drainage area on the Musselshell River -- apparently as a result of valley storage.

To determine flood magnitudes for selected exceedance probabilities for any ungaged site in Montana, locate the site on the map (fig. 1) and determine in which region it is located and if it is on a gaged stream.

1. If the site is on the Bitterroot, Clark Fork, Milk, Missouri, Musselshell, Powder, Sun, or Yellowstone Rivers, interpolate the desired flood magnitudes from the discharge versus drainage-area curves in figures 14-21.
2. If the site is on a gaged stream and has a drainage area within 5 percent of that of the nearest gage, use the weighted-flow magnitudes for the gage given in table 1.
3. If the site is on a gaged stream and has a drainage area within 50 percent of that at the gage, use equation 5 to determine the desired flood magnitudes.

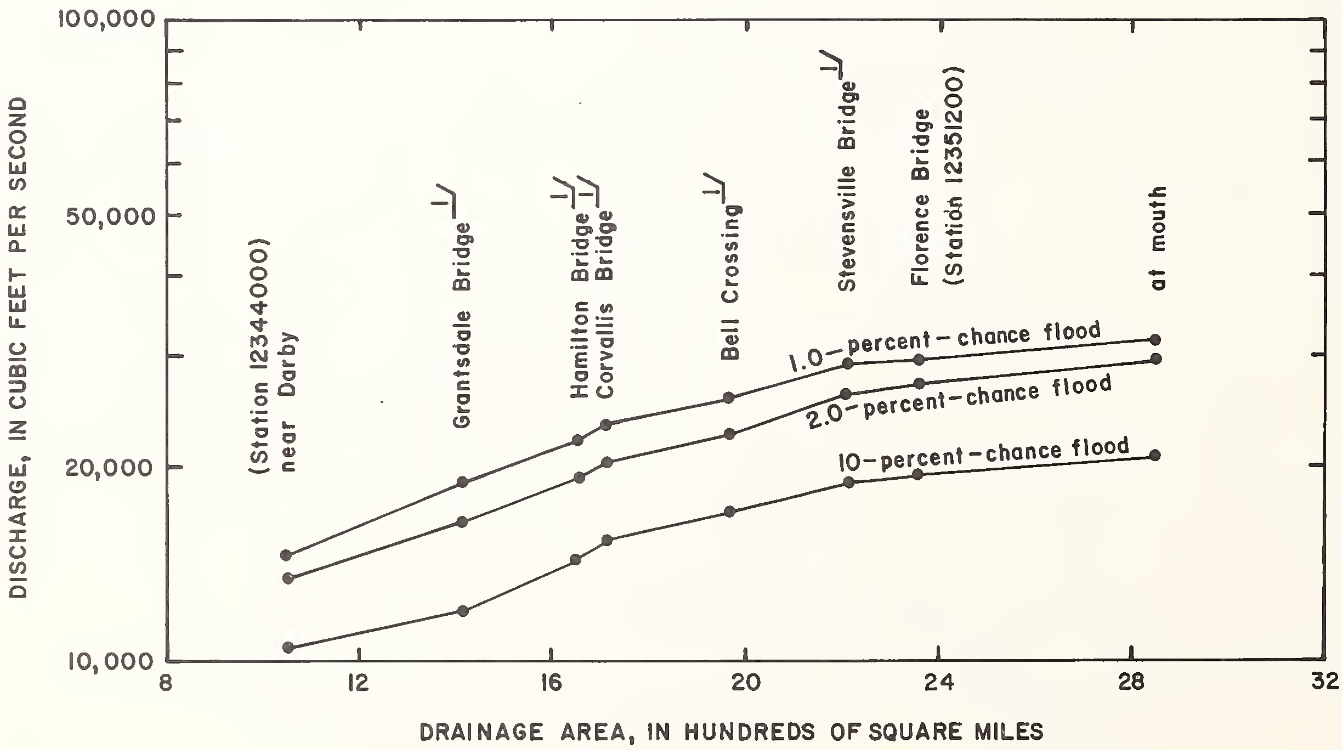


Figure 14.--Flood frequency for the Bitterroot River.

4. If the site is on an ungaged stream or on a gaged stream where the drainage area at the site differs from the drainage area at the gage by more than 50 percent, use the appropriate regression equation to calculate flood magnitudes as follows:

   a. Select the appropriate regression equation from table 3, based on the region the site is in; and

   b. Determine the required basin characteristics from illustrations in this report or the best available topographic map as required.

5. If the drainage basin for the site in question lies in two regions, determine a weighted average flood magnitude as follows:

   a. Using the total drainage area and the appropriate regression equation, determine the flood-magnitude that would result if the entire drainage were located within each of the 2 regions;

   b. Measure that part of the total drainage area that lies in each of the two adjoining regions;

   c. Multiply the flood magnitude determined in step a. for each region by the ratio of the drainage area within that region to the total drainage area and add the two results to obtain a weighted average flood magnitude.

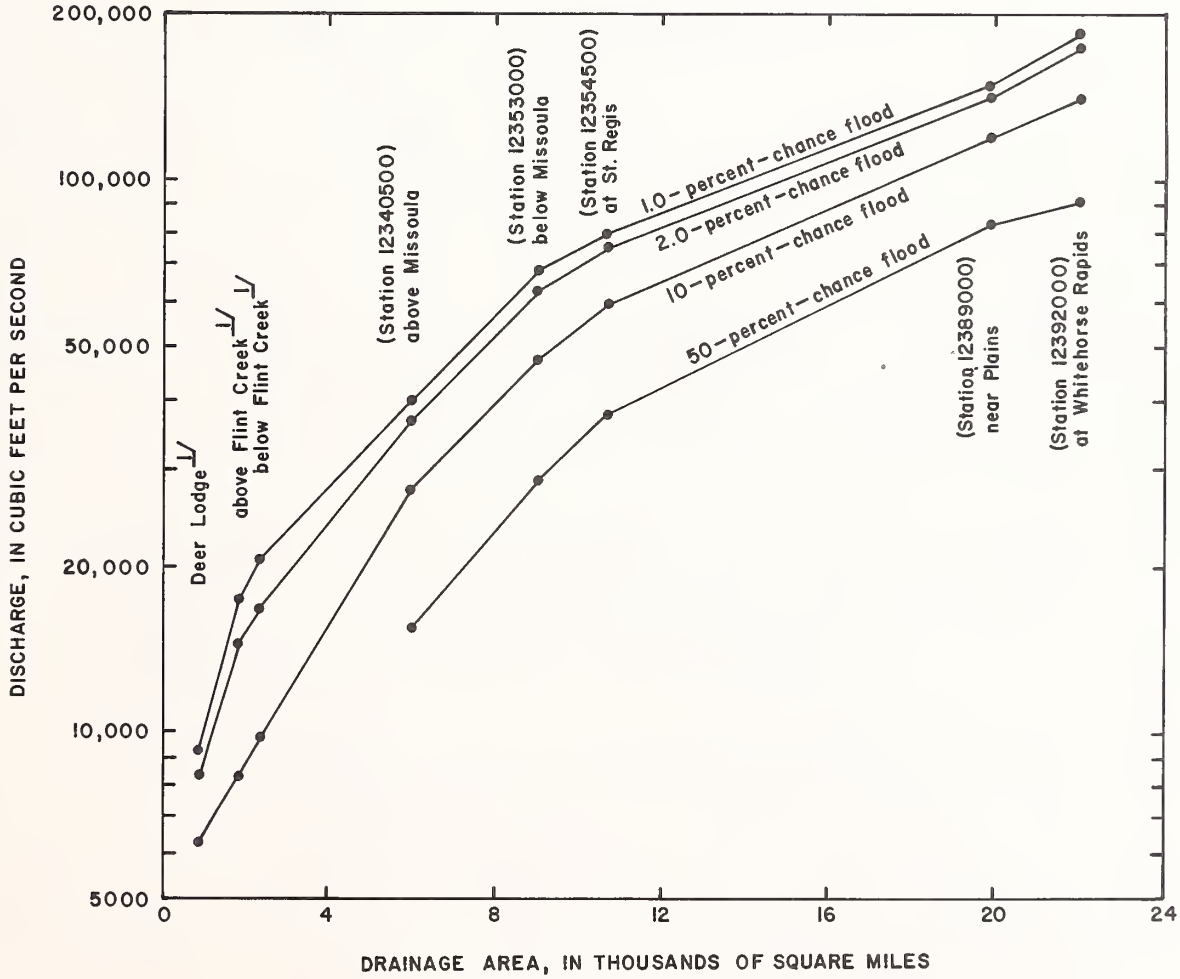


Figure 15.--Flood frequency for the Clark Fork River.

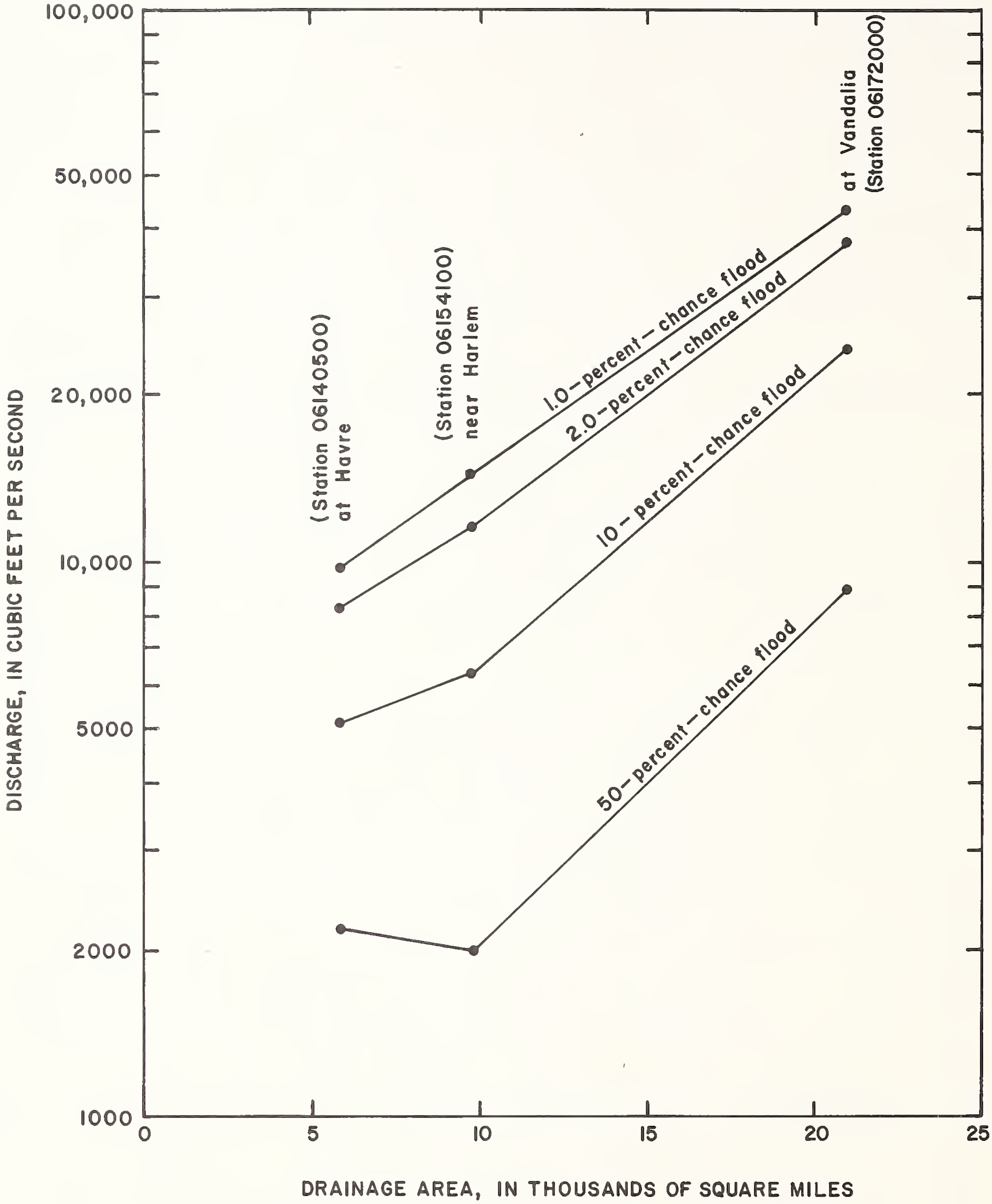


Figure 16.--Flood frequency for the Milk River.

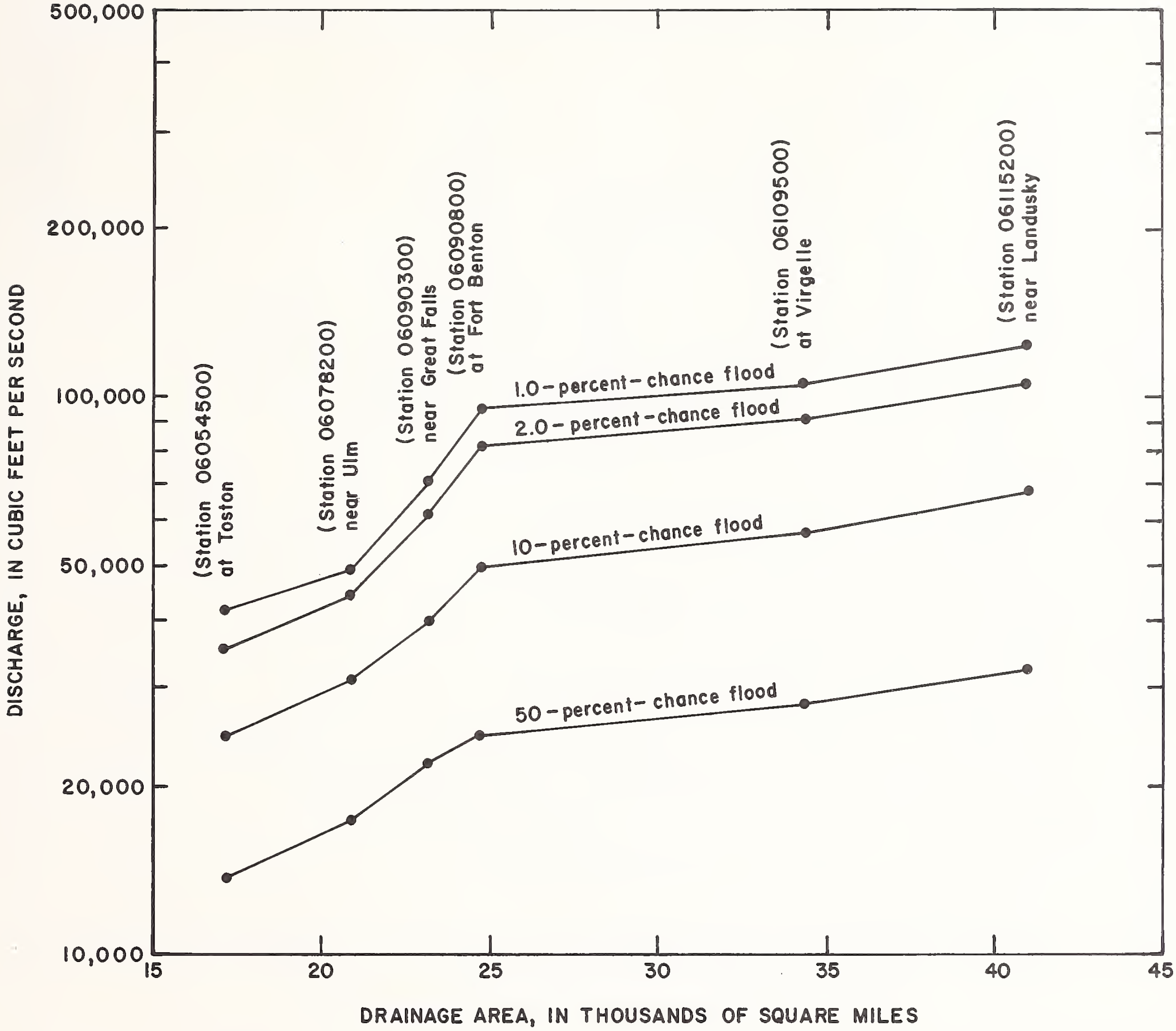


Figure 17.--Flood frequency for the Missouri River.

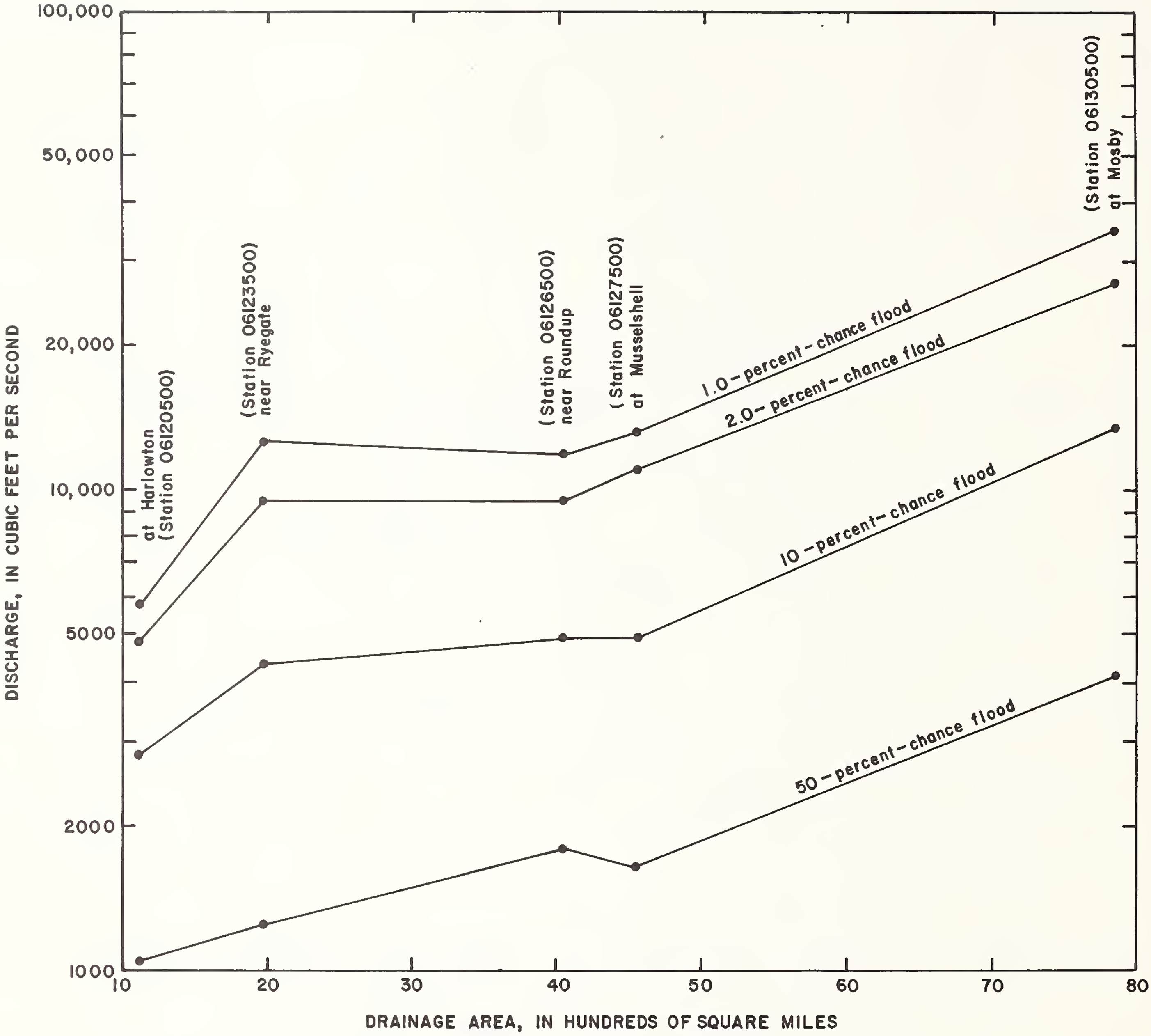


Figure 18.--Flood frequency for the Musselshell River.

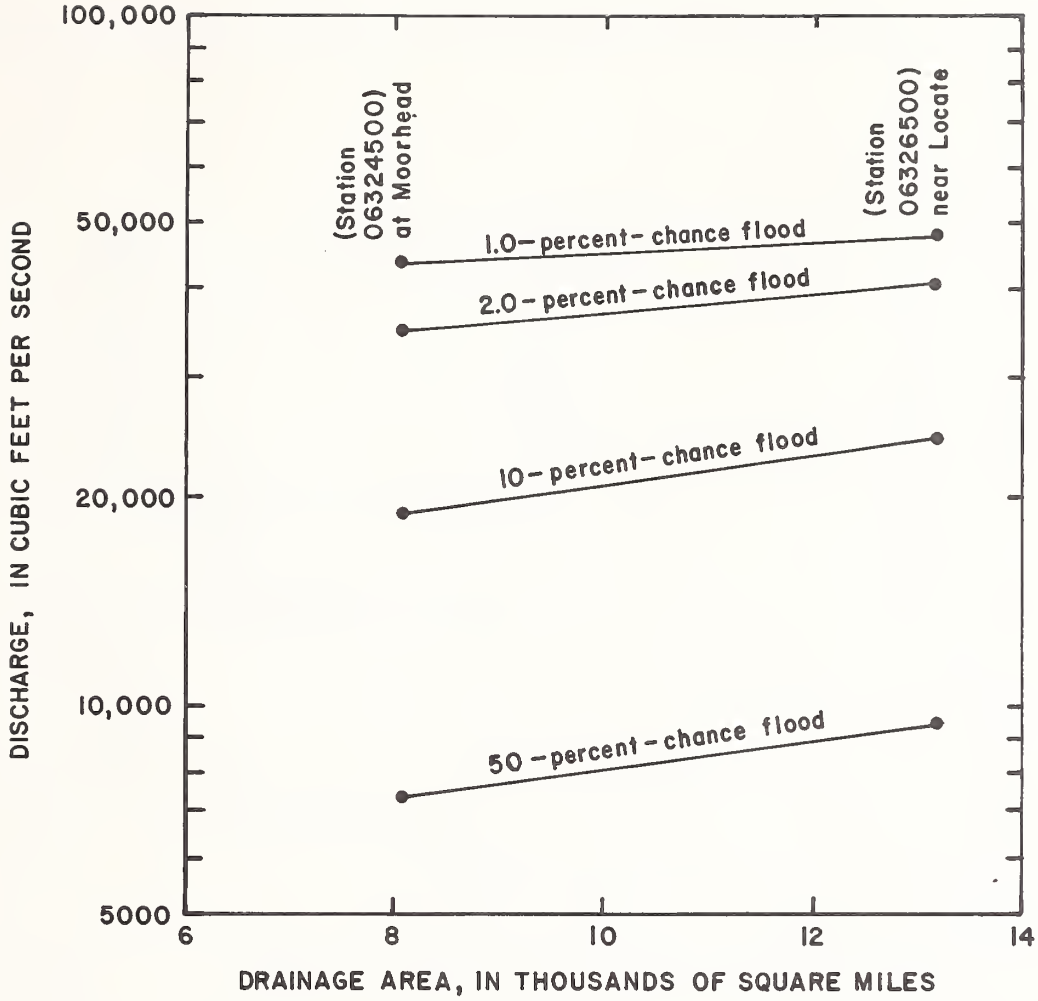


Figure 19.--Flood frequency for the Powder River.

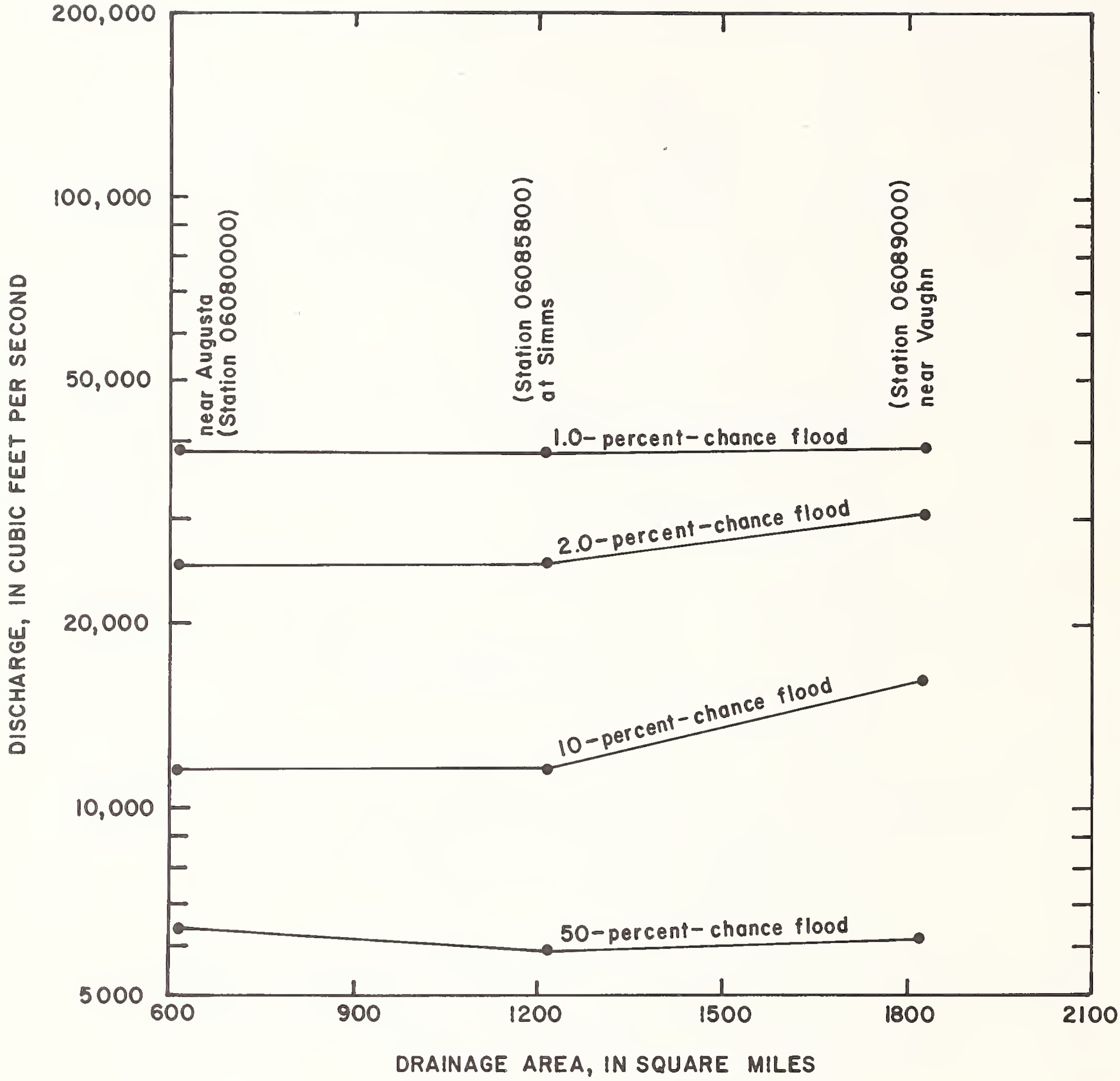


Figure 20.--Flood frequency for the Sun River.

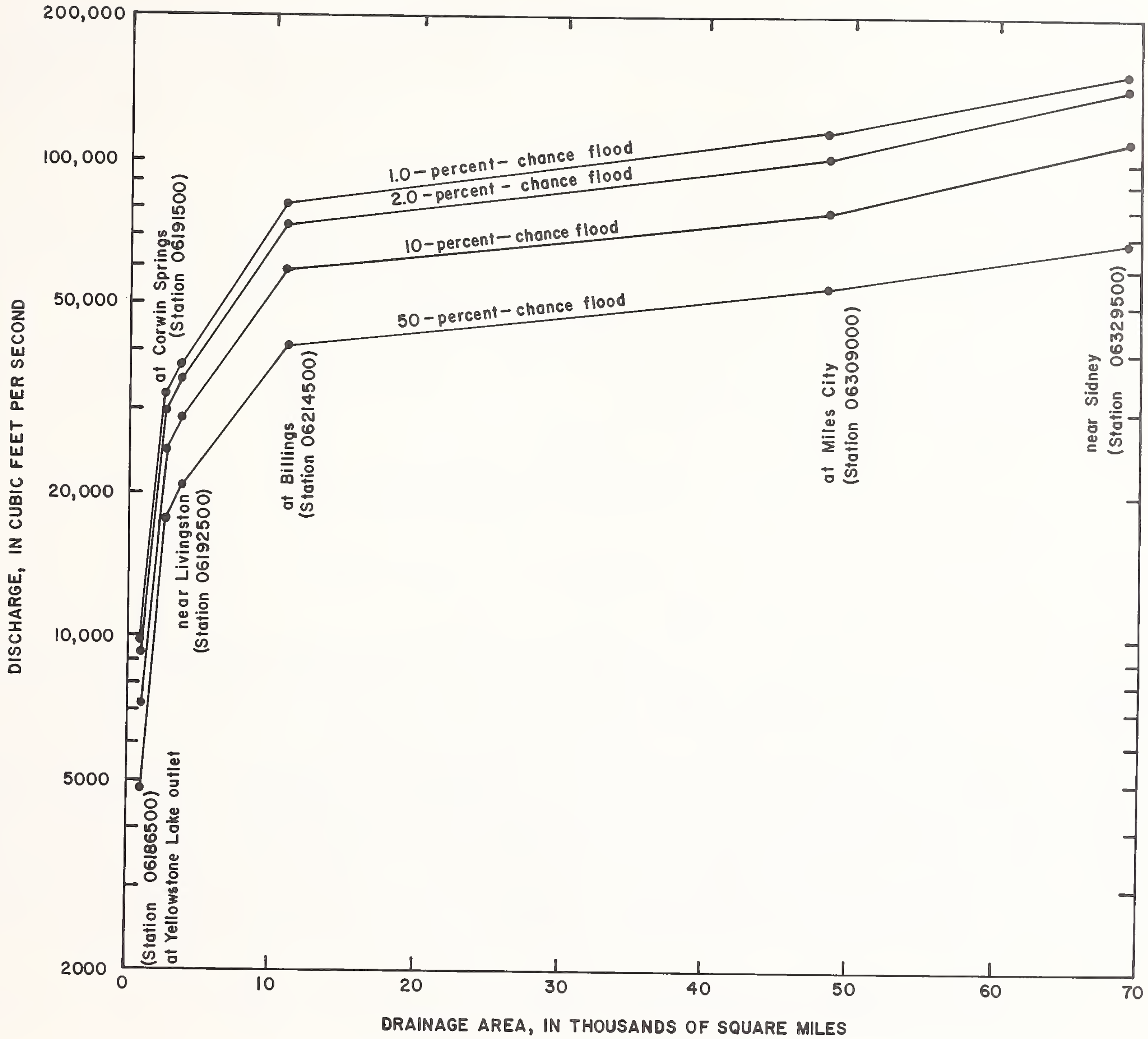


Figure 21.--Flood frequency for the Yellowstone River.

ILLUSTRATIVE EXAMPLES

The procedure for determining flood magnitudes at ungaged sites is shown by the following examples:

Example 1. (Using the regression equations)

Determine the flood magnitude for an exceedance probability of 1 percent (recurrence interval of 100 years) for an ungaged site in the Southeast Plains Region where the drainage area is 14.6 square miles, the percentage of forest cover (F) is 17, and the basin mean geographical factor (G_f) from figure 5 is 1.2.

From the Southeast Plains Region equations (table 3), the flood magnitude for a 1-percent exceedance probability is:

$$
\begin{aligned}
Q_{1\%} &= 2{,}770\ A^{0.53}\ (F+10)^{-0.76} G_f \\
&= (2{,}770)(14.6)^{0.53}\ (27)^{-0.76}(1.2) \\
&= (2{,}770)(4.14)(0.0817)(1.2) \\
&= 1{,}120 \text{ cubic feet per second}
\end{aligned}
$$

Example 2. (Using the regression equations when the drainage basin is in two regions

Determine the flood magnitude for an exceedance probability of 2 percent (recurrence interval of 50 years) for a site in northeastern Montana where 10.5 square miles of the total drainage area is in the Northeast Plains Region and 32.2 square miles of the total drainage area is in the East-Central Plains Region. That part of the drainage basin in the Northeast Plains Region has a mean basin elevation (E) of 3,120 feet, an average January minimum temperature (TI) from figure 4 of -2 degrees Fahrenheit, and a basin mean geographical factor from figure 5 of 1.1.

From the Northeast Plains Region equations, the flood magnitude for a 2-percent exceedance probability is:

$$
\begin{aligned}
Q_{2\%} &= 519\ A^{0.55}\ (E/1000)^{-0.38}\ (TI+10)^{-0.26}\ G_f \\
&= (519)(42.7)^{0.55}\ (3.12)^{-0.38}\ (8.0)^{-0.26}\ (1.1) \\
&= (519)(7.88)(0.649)(0.582)(1.1) \\
&= 1{,}700 \text{ cubic feet per second}
\end{aligned}
$$

That part of the drainage basin in the East-Central Plains has a mean basin elevation (E) of 2,980 feet and a basin mean geographical factor of 1.2. The flood magnitude for a 2-percent exceedance probability as determined from the East-Central Region equations is:

$$Q_{2\%} = 1{,}460\ A^{0.47}(E/1000)^{-0.99}\ G_f$$

$$= (1{,}460)(42.7)^{0.47}\ (2.98)^{-0.99}(1.2)$$

$$= (1{,}460)(5.84)(0.339)(1.2)$$

$$= 3{,}470 \text{ cubic feet per second}$$

The weighted average flood magnitude for a 2-percent exceedance probability is thus:

$$Q_{2\%} = 1{,}700\left(\frac{10.5}{42.7}\right) + 3{,}470\left(\frac{32.2}{42.7}\right)$$

$$= 3{,}030 \text{ cubic feet per second}$$

<u>Example 3. (Transferring data from gaged site)</u>

Determine the flood magnitude for a recurrence interval of 100 years (exceedance probability of 1.0 percent) for the Tobacco River near Eureka, Mont., at an ungaged site where the drainage area is 305 square miles. From table 2 (West Region), the drainage area of the gage site (12301300) is 440 square miles and from table 1 the weighted value for the 1-percent flood is 3,960 cubic feet per second. From the equations for the West Region where F is greater than 15 percent (table 3), the exponent on drainage area (A) for a 1-percent flood is 0.84. Using equation 5, the flood magnitude for a 1-percent exceedance probability at the site is:

$$Q_{1\%} = (305/440)^{0.84}\ (3{,}960)$$

$$= (0.735)\ (3{,}960)$$

$$= 2{,}910 \text{ cubic feet per second}$$

SUMMARY

Multiple-regression equations relating annual flood magnitude to various basin characteristics for exceedance probabilities of 50, 20, 10, 4, 2 and 1 percent were developed for eight regions in Montana. The maximum number of basin characteristics found to be significant in the equations in any region was four, including a geographical factor. The minimum number of basin characteristics included in any of the equations was two. The most significant basin characteristic in all regions was drainage area. The standard error of estimate for an exceedance probability of 1 percent ranged from 39 to 83 percent when using the geographical factor. For an exceedance probability of 50 percent, the standard error of estimate ranged from 52 to 105 percent considering the geographical factor. The standard error of estimate for all exceedance probabilities was improved significantly compared to previous regression analyses.

A technique for transferring gage data upstream or downstream from the gaged site using a drainage-area ratio adjustment was also presented. Curves relating flood magnitude to drainage area were prepared for the major streams having several gaged sites.

Flood magnitude-frequency data at streamflow-gaging stations were weighted with predicted values from the regression equations, and the results are presented in tabular form. The use of weighted values at the gaged sites provides more reliable flood magnitude estimates than the use of station data only.

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Table 1.--*Annual flood magnitude-frequency data for streamflow-gaging stations*

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
	DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES							
				WEST REGION				
12300500	Q(STATION)	737	1130	1420	1820	2140	2480	1810
	Q(PREDICTED)	513	804	1010	1270	1480	1710	-
	Q(WEIGHTED)	725	1100	1370	1740	2030	2310	-
12300800	Q(STATION)	138	191	226	272	306	340	310
	Q(PREDICTED)	150	232	290	365	422	482	-
	Q(WEIGHTED)	139	195	235	287	328	374	-
12301300	Q(STATION)	1580	2190	2580	3070	3430	3780	2810
	Q(PREDICTED)	1740	2510	3010	3620	4080	4560	-
	Q(WEIGHTED)	1590	2220	2640	3150	3550	3960	-
12301700	Q(STATION)	6	10	14	19	24	29	14
	Q(PREDICTED)	6	11	15	21	27	34	-
	Q(WEIGHTED)	7	10	14	19	25	31	-
12301800	Q(STATION)	65	111	149	203	248	299	230
	Q(PREDICTED)	36	64	86	116	140	171	-
	Q(WEIGHTED)	62	103	135	181	216	252	-
12302000	Q(STATION)	3400	5150	6340	7830	8940	10000	8720
	Q(PREDICTED)	4050	5710	6780	8070	9040	10000	-
	Q(WEIGHTED)	3430	5190	6380	7860	8950	10000	-
12302400	Q(STATION)	12	30	48	78	106	139	200
	Q(PREDICTED)	22	38	50	66	79	93	-
	Q(WEIGHTED)	13	31	48	76	101	128	-
12302500	Q(STATION)	586	915	1160	1510	1790	2100	2000
	Q(PREDICTED)	439	635	766	931	1050	1160	-
	Q(WEIGHTED)	578	892	1110	1430	1670	1900	-
12303100	Q(STATION)	225	325	391	474	536	597	709
	Q(PREDICTED)	267	388	469	574	650	714	-
	Q(WEIGHTED)	228	332	402	491	559	628	-
12303500	Q(STATION)	2590	3240	3630	4110	4450	4780	7000
	Q(PREDICTED)	3420	4500	5140	5930	6460	6840	-
	Q(WEIGHTED)	2660	3400	3900	4500	4950	5430	-
12304250	Q(STATION)	29	46	58	74	87	100	100
	Q(PREDICTED)	25	44	59	80	97	118	-
	Q(WEIGHTED)	29	46	58	75	89	105	-
12304300	Q(STATION)	133	182	213	252	280	308	350
	Q(PREDICTED)	112	173	216	274	317	360	-
	Q(WEIGHTED)	132	181	213	256	287	321	-
12304400	Q(STATION)	164	248	306	382	439	497	400
	Q(PREDICTED)	158	240	297	372	428	481	-
	Q(WEIGHTED)	164	247	304	380	436	492	-
12304500	Q(STATION)	7590	9820	11200	12800	14000	15100	13400
	Q(PREDICTED)	6520	8770	10100	11700	12900	13900	-
	Q(WEIGHTED)	7540	9740	11100	12700	13800	14900	-
12323300	Q(STATION)	21	50	77	123	165	214	123
	Q(PREDICTED)	11	23	33	50	64	86	-
	Q(WEIGHTED)	20	47	71	111	146	183	-
12323500	Q(STATION)	188	295	370	469	545	623	692
	Q(PREDICTED)	135	245	323	436	531	658	-
	Q(WEIGHTED)	183	288	361	462	541	635	-
12324100	Q(STATION)	360	484	563	660	731	800	580
	Q(PREDICTED)	309	490	619	789	920	1070	-
	Q(WEIGHTED)	356	485	572	684	771	874	-
12324700	Q(STATION)	43	82	115	164	207	256	133
	Q(PREDICTED)	12	25	36	52	67	87	-
	Q(WEIGHTED)	41	77	105	147	182	217	-
12324800	Q(STATION)	8	14	18	23	28	65	23
	Q(PREDICTED)	40	75	104	144	179	226	-
	Q(WEIGHTED)	11	21	33	47	63	113	-

Table 1.--*Annual flood magnitude-frequency data for streamflow-gaging stations*--Continued

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
	DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES							
	WEST REGION--Continued							
12330000	Q(STATION)	375	553	677	840	965	1090	1460
	Q(PREDICTED)	410	647	817	1030	1210	1400	-
	Q(WEIGHTED)	376	558	687	857	991	1130	-
12332000	Q(STATION)	912	1240	1440	1670	1830	1980	1590
	Q(PREDICTED)	740	1110	1360	1680	1920	2190	-
	Q(WEIGHTED)	907	1230	1430	1670	1840	2010	-
12335500	Q(STATION)	504	915	1250	1730	2130	2560	1800
	Q(PREDICTED)	495	807	1030	1330	1570	1860	-
	Q(WEIGHTED)	504	909	1230	1690	2070	2460	-
12338500	Q(STATION)	5230	8210	10500	13600	16200	18900	17600
	Q(PREDICTED)	6310	8890	10500	12500	13900	1550	-
	Q(WEIGHTED)	5280	8260	10500	13500	15800	15400	-
12339900	Q(STATION)	94	156	202	264	314	365	300
	Q(PREDICTED)	39	71	97	134	164	205	-
	Q(WEIGHTED)	91	148	188	243	286	326	-
12340000	Q(STATION)	9360	14000	16900	20400	22900	25200	19200
	Q(PREDICTED)	8730	12000	14000	16400	18000	19900	-
	Q(WEIGHTED)	9340	13900	16700	20100	22400	24500	-
12340200	Q(STATION)	17	26	33	41	47	54	50
	Q(PREDICTED)	18	34	47	65	80	100	-
	Q(WEIGHTED)	17	27	35	46	55	68	-
12341000	Q(STATION)	1310	1740	2000	2310	2530	2740	2400
	Q(PREDICTED)	363	561	700	877	1020	1170	-
	Q(WEIGHTED)	1200	1540	1690	1920	2050	2130	-
12343400	Q(STATION)	1930	2820	3380	4050	4530	5000	4000
	Q(PREDICTED)	1460	2130	2570	3120	3530	3970	-
	Q(WEIGHTED)	1910	2780	3320	3960	4420	4840	-
12344300	Q(STATION)	8	14.	19	24	29	33	25
	Q(PREDICTED)	17	33	46	64	80	102	-
	Q(WEIGHTED)	9	16	22	30	38	49	-
12345800	Q(STATION)	148	209	248	294	327	359	265
	Q(PREDICTED)	95	144	178	223	256	288	-
	Q(WEIGHTED)	144	201	237	280	311	339	-
12346500	Q(STATION)	656	853	974	1120	1220	1320	1210
	Q(PREDICTED)	428	652	807	1000	1160	1320	-
	Q(WEIGHTED)	646	839	957	1110	1210	1320	-
12347500	Q(STATION)	607	765	856	959	1030	1090	1170
	Q(PREDICTED)	433	614	731	881	989	1080	-
	Q(WEIGHTED)	600	755	844	950	1020	1090	-
12348500	Q(STATION)	105	137	156	178	194	209	170
	Q(PREDICTED)	106	174	224	292	345	407	-
	Q(WEIGHTED)	105	141	166	197	223	259	-
12350000	Q(STATION)	701	894	1010	1140	1230	1320	1340
	Q(PREDICTED)	461	650	773	927	1040	1130	-
	Q(WEIGHTED)	686	870	977	1100	1190	1270	-
12350200	Q(STATION)	109	159	191	231	259	287	200
	Q(PREDICTED)	59	93	117	149	173	197	-
	Q(WEIGHTED)	105	151	179	215	240	261	-
12350500	Q(STATION)	808	1060	1210	1380	1500	1620	1300
	Q(PREDICTED)	495	695	824	989	1100	1200	-
	Q(WEIGHTED)	791	1030	1160	1320	1430	1530	-
12351000	Q(STATION)	339	507	619	761	865	969	1100
	Q(PREDICTED)	313	491	616	780	906	1050	-
	Q(WEIGHTED)	338	506	619	763	869	980	-
12351400	Q(STATION)	47	79	102	132	156	180	104
	Q(PREDICTED)	52	93	125	171	209	259	-
	Q(WEIGHTED)	47	81	106	139	168	203	-

STATION		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
				WEST REGION--Continued				
12352000	Q(STATION)	1520	1840	2020	2230	2380	2510	2660
	Q(PREDICTED)	2310	3160	3670	4310	4760	5150	-
	Q(WEIGHTED)	1600	2040	2360	2730	3040	3430	-
12352200	Q(STATION)	10	25	39	62	82	105	56
	Q(PREDICTED)	22	39	52	70	85	104	-
	Q(WEIGHTED)	11	27	41	64	83	105	-
12353400	Q(STATION)	30	69	104	158	206	260	170
	Q(PREDICTED)	51	87	116	154	185	223	-
	Q(WEIGHTED)	32	71	106	157	201	249	-
12353800	Q(STATION)	72	115	145	184	213	242	230
	Q(PREDICTED)	84	136	173	223	262	305	-
	Q(WEIGHTED)	73	117	149	191	223	259	-
12353850	Q(STATION)	34	55	69	86	99	113	66
	Q(PREDICTED)	30	49	63	83	98	114	-
	Q(WEIGHTED)	34	54	68	86	99	113	-
12354000	Q(STATION)	4190	6080	7310	8820	9920	11000	11000
	Q(PREDICTED)	2200	2970	3450	4030	4440	4790	-
	Q(WEIGHTED)	4100	5850	6900	8210	9100	9770	-
12354100	Q(STATION)	173	245	290	346	385	423	295
	Q(PREDICTED)	141	215	266	333	384	436	-
	Q(WEIGHTED)	170	241	286	343	385	427	-
12363900	Q(STATION)	15	24	32	44	53	64	40
	Q(PREDICTED)	21	36	49	66	80	97	-
	Q(WEIGHTED)	15	25	35	48	59	74	-
12364000	Q(STATION)	454	874	1220	1740	2170	2650	1380
	Q(PREDICTED)	778	1200	1490	1870	2150	2490	-
	Q(WEIGHTED)	491	931	1280	1780	2160	2590	-
12365000	Q(STATION)	1520	2500	3170	4020	4650	5270	4330
	Q(PREDICTED)	1890	2740	3280	3960	4470	5010	-
	Q(WEIGHTED)	1540	2520	3180	4010	4620	5220	-
12366000	Q(STATION)	820	1090	1250	1450	1580	1720	1580
	Q(PREDICTED)	824	1220	1480	1800	2050	2310	-
	Q(WEIGHTED)	820	1100	1270	1490	1640	1830	-
12370500	Q(STATION)	38	79	115	172	222	280	131
	Q(PREDICTED)	66	118	160	218	266	330	-
	Q(WEIGHTED)	40	83	121	179	230	292	-
12370900	Q(STATION)	8	19	29	48	65	88	44
	Q(PREDICTED)	25	41	54	71	84	99	-
	Q(WEIGHTED)	9	22	33	53	69	91	-
12371100	Q(STATION)	28	57	84	126	163	206	104
	Q(PREDICTED)	52	84	108	140	165	192	-
	Q(WEIGHTED)	29	59	87	128	163	203	-
12374300	Q(STATION)	89	165	227	318	395	478	250
	Q(PREDICTED)	114	192	251	330	394	473	-
	Q(WEIGHTED)	91	168	231	320	395	477	-
12375700	Q(STATION)	25	49	68	96	119	144	100
	Q(PREDICTED)	11	21	30	43	55	71	-
	Q(WEIGHTED)	24	46	61	85	104	122	-
12378000	Q(STATION)	463	718	900	1140	1330	1520	1700
	Q(PREDICTED)	533	778	940	1150	1300	1450	-
	Q(WEIGHTED)	470	728	909	1140	1320	1490	-
12389500	Q(STATION)	2690	4270	5360	6740	7770	8780	6190
	Q(PREDICTED)	4130	5640	6560	7690	8490	9230	-
	Q(WEIGHTED)	2760	4380	5500	6870	7890	8870	-
12390700	Q(STATION)	1790	2670	3260	3990	4520	5050	5490
	Q(PREDICTED)	1800	2470	2900	3410	3780	4100	-
	Q(WEIGHTED)	1790	2650	3220	3910	4400	4840	-

STATION		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
				NORTHWEST REGION				
5010000	Q(STATION)	1550	1900	2210	3050	5600	12000	12000
	Q(PREDICTED)	2310	2930	3370	4250	5970	9180	-
	Q(WEIGHTED)	1620	2070	2450	3380	5780	10600	-
5011000	Q(STATION)	1950	2680	3210	4800	9200	16700	16400
	Q(PREDICTED)	2840	3770	4440	5690	7890	11800	-
	Q(WEIGHTED)	1970	2730	3290	4880	8950	15700	-
5012500	Q(STATION)	540	680	790	1000	1500	2600	5930
	Q(PREDICTED)	500	703	863	1150	1680	2670	-
	Q(WEIGHTED)	536	684	805	1040	1590	2630	-
5013000	Q(STATION)	4600	5850	7000	9000	15000	25700	25700
	Q(PREDICTED)	5820	7240	8220	10200	13900	20400	-
	Q(WEIGHTED)	4640	5930	7090	9130	14700	24500	-
5014000	Q(STATION)	186	262	314	382	433	486	540
	Q(PREDICTED)	120	172	216	295	454	773	-
	Q(WEIGHTED)	182	253	301	366	441	592	-
5014500	Q(STATION)	1010	1310	1510	1900	3300	6700	6700
	Q(PREDICTED)	1010	1260	1450	1820	2620	4190	-
	Q(WEIGHTED)	1020	1310	1510	1890	3160	6190	-
5015000	Q(STATION)	195	310	400	620	1000	1800	720
	Q(PREDICTED)	274	361	431	561	847	1420	-
	Q(WEIGHTED)	204	320	408	600	915	1590	-
6073000	Q(STATION)	1140	2000	2750	4300	6200	10500	17400
	Q(PREDICTED)	1720	2840	3780	5360	7430	10700	-
	Q(WEIGHTED)	1170	2090	2890	4500	6650	10600	-
6078500	Q(STATION)	3100	4000	4650	6200	10500	17500	51100
	Q(PREDICTED)	4170	6250	7850	10600	14400	20400	-
	Q(WEIGHTED)	3170	4260	5140	7110	12000	18700	-
6079600	Q(STATION)	119	276	450	800	1350	2500	4360
	Q(PREDICTED)	216	445	670	1060	1550	2310	-
	Q(WEIGHTED)	129	306	501	879	1450	2400	-
6080000	Q(STATION)	6400	9600	12000	17100	24500	38000	59700
	Q(PREDICTED)	9590	13600	16400	21500	28400	39400	-
	Q(WEIGHTED)	6600	10100	12600	18000	26000	38600	-
6081500	Q(STATION)	150	350	540	890	1250	1470	1150
	Q(PREDICTED)	566	1190	1810	2870	4010	5570	-
	Q(WEIGHTED)	183	469	773	1380	2490	3350	-
6084500	Q(STATION)	855	2190	3450	5450	7200	9160	12000
	Q(PREDICTED)	1020	2090	3100	4830	6650	9120	-
	Q(WEIGHTED)	868	2180	3390	5300	6950	9140	-
6092000	Q(STATION)	3600	5200	6700	9900	15500	29000	100000
	Q(PREDICTED)	4140	6520	8370	11600	15600	21700	-
	Q(WEIGHTED)	3620	5290	6860	10100	15500	26900	-
6092500	Q(STATION)	1600	2400	3000	4300	7100	13000	49700
	Q(PREDICTED)	1770	2860	3740	5250	7240	10400	-
	Q(WEIGHTED)	1610	2460	3120	4500	7160	11900	-
6098000	Q(STATION)	490	1340	2450	5100	8700	14000	21600
	Q(PREDICTED)	1130	2170	3130	4740	6560	9140	-
	Q(WEIGHTED)	532	1440	2560	5020	7830	12000	-
6102500	Q(STATION)	1400	2650	3900	6400	10000	17500	54600
	Q(PREDICTED)	1370	2340	3160	4680	6350	9140	-
	Q(WEIGHTED)	1400	2600	3760	5960	8310	13600	-
6132200	Q(STATION)	380	790	1200	2100	3400	6200	12000
	Q(PREDICTED)	746	1300	1780	2590	3660	5320	-
	Q(WEIGHTED)	412	869	1320	2230	3520	5770	-
12335000	Q(STATION)	2110	3730	5010	6850	8380	10000	9500
	Q(PREDICTED)	1220	2650	4040	6410	8550	11100	-
	Q(WEIGHTED)	2020	3550	4800	6720	8470	10600	-

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES						
				NORTHWEST REGION--Continued				
12355000	Q(STATION)	7430	10300	12100	14300	16000	17600	16300
	Q(PREDICTED)	6460	8390	9710	12200	16300	23200	-
	Q(WEIGHTED)	7400	10200	11900	14100	16100	19000	-
12355500	Q(STATION)	20600	26300	30000	35200	39500	44500	69100
	Q(PREDICTED)	7890	12700	16500	22700	29200	38000	-
	Q(WEIGHTED)	20200	25600	29000	33900	37200	43000	-
12356000	Q(STATION)	160	225	275	380	620	1100	3820
	Q(PREDICTED)	110	198	280	418	627	989	-
	Q(WEIGHTED)	157	222	276	388	623	1060	-
12356500	Q(STATION)	410	620	800	1040	1560	2350	8340
	Q(PREDICTED)	295	484	646	923	1350	2080	-
	Q(WEIGHTED)	396	591	758	999	1440	2190	-
12357000	Q(STATION)	9800	14000	17000	22000	27000	34500	75300
	Q(PREDICTED)	7590	10000	11700	14800	19600	27700	-
	Q(WEIGHTED)	9650	13500	16200	20500	24000	31700	-
12357300	Q(STATION)	130	235	335	515	820	1400	10000
	Q(PREDICTED)	53	96	136	207	321	533	-
	Q(WEIGHTED)	123	212	293	430	575	968	-
12357400	Q(STATION)	2	5	9	15	22	32	10
	Q(PREDICTED)	2	5	8	15	24	43	-
	Q(WEIGHTED)	2	5	9	15	23	38	-
12358500	Q(STATION)	22000	29000	35000	43000	52000	66000	140000
	Q(PREDICTED)	19400	23100	25400	30500	39500	55100	-
	Q(WEIGHTED)	21900	28500	34000	41200	48300	62700	-
12359000	Q(STATION)	15300	18900	21000	24000	26000	30000	36700
	Q(PREDICTED)	12500	15800	17900	22100	28800	40100	-
	Q(WEIGHTED)	15100	18400	20400	23500	27300	34900	-
12359500	Q(STATION)	3700	4450	4900	5500	6000	6900	20200
	Q(PREDICTED)	2780	3800	4550	5900	8070	11800	-
	Q(WEIGHTED)	3570	4290	4790	5660	7290	9980	-
12359800	Q(STATION)	18500	24600	29000	34600	38500	45000	50900
	Q(PREDICTED)	15000	18800	21100	25900	33700	46500	-
	Q(WEIGHTED)	18100	23600	27200	32000	36000	45800	-
12360000	Q(STATION)	1400	1950	2310	2890	3050	4100	5830
	Q(PREDICTED)	689	1050	1350	1850	2640	4000	-
	Q(WEIGHTED)	1320	1770	2060	2540	2820	4040	-
12361000	Q(STATION)	1860	2430	2800	3210	3600	4100	5020
	Q(PREDICTED)	593	1040	1430	2090	2940	4290	-
	Q(WEIGHTED)	1780	2270	2600	2990	3340	4170	-
12361500	Q(STATION)	1290	1880	2290	2820	3230	3650	3780
	Q(PREDICTED)	692	1000	1250	1670	2430	3800	-
	Q(WEIGHTED)	1220	1700	2020	2440	2780	3730	-
12362500	Q(STATION)	25000	34500	40200	47500	53700	61500	78000
	Q(PREDICTED)	13500	18800	22500	29000	37200	49700	-
	Q(WEIGHTED)	24600	33400	38500	45000	49100	58100	-
				SOUTHWEST REGION				
6011000	Q(STATION)	711	932	1070	1220	1330	1430	1360
	Q(PREDICTED)	738	986	1160	1340	1470	1590	-
	Q(WEIGHTED)	714	943	1090	1260	1370	1470	-
6013200	Q(STATION)	5	19	37	75	116	170	28
	Q(PREDICTED)	12	24	32	46	57	69	-
	Q(WEIGHTED)	6	21	35	62	92	129	-
6013400	Q(STATION)	62	115	156	213	258	305	197
	Q(PREDICTED)	127	195	242	302	348	394	-
	Q(WEIGHTED)	73	140	190	252	295	341	-

Table 1.--*Annual flood magnitude-frequency data for streamflow-gaging stations*--Continued

STATION		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
				SOUTHWEST REGION--Continued				
6013500	Q(STATION)	345	522	639	784	890	994	909
	Q(PREDICTED)	512	695	820	957	1060	1150	-
	Q(WEIGHTED)	361	557	687	836	937	1040	-
6015500	Q(STATION)	391	681	893	1180	1400	1620	1870
	Q(PREDICTED)	624	847	1000	1170	1290	1410	-
	Q(WEIGHTED)	407	706	914	1180	1380	1580	-
6017500	Q(STATION)	196	284	341	410	461	509	426
	Q(PREDICTED)	449	610	719	841	931	1010	-
	Q(WEIGHTED)	228	367	464	568	622	678	-
6019500	Q(STATION)	936	1200	1370	1560	1690	1830	1700
	Q(PREDICTED)	741	982	1150	1320	1450	1570	-
	Q(WEIGHTED)	923	1170	1330	1510	1640	1780	-
6019800	Q(STATION)	21	38	50	68	82	96	90
	Q(PREDICTED)	19	36	50	70	86	104	-
	Q(WEIGHTED)	21	37	51	69	83	99	-
6025300	Q(STATION)	101	143	170	204	229	253	180
	Q(PREDICTED)	86	137	173	222	259	298	-
	Q(WEIGHTED)	99	141	171	212	241	271	-
6025500	Q(STATION)	7230	10400	12400	14700	16300	17900	23000
	Q(PREDICTED)	4880	5710	6340	6790	7160	7430	-
	Q(WEIGHTED)	7110	9880	11500	13300	14800	16300	-
6027700	Q(STATION)	135	190	227	274	309	344	250
	Q(PREDICTED)	81	137	179	239	286	337	-
	Q(WEIGHTED)	128	177	211	261	301	342	-
6029000	Q(STATION)	65	95	116	143	164	186	126
	Q(PREDICTED)	65	107	136	177	207	240	-
	Q(WEIGHTED)	65	98	123	156	180	206	-
6030300	Q(STATION)	11	41	82	171	275	423	169
	Q(PREDICTED)	15	41	68	119	168	232	-
	Q(WEIGHTED)	11	41	78	153	241	362	-
6030500	Q(STATION)	148	246	323	431	520	617	582
	Q(PREDICTED)	85	143	184	243	288	337	-
	Q(WEIGHTED)	135	207	258	335	407	482	-
6033000	Q(STATION)	1100	1760	2250	2930	3480	4070	3500
	Q(PREDICTED)	1330	1890	2290	2740	3090	3420	-
	Q(WEIGHTED)	1110	1780	2260	2890	3410	3950	-
6034700	Q(STATION)	25	163	437	1260	2490	4610	2130
	Q(PREDICTED)	26	109	228	522	885	1440	-
	Q(WEIGHTED)	25	146	355	938	1830	3330	-
6034800	Q(STATION)	1	6	24	116	320	800	96
	Q(PREDICTED)	4	18	41	103	184	316	-
	Q(WEIGHTED)	1	10	31	110	264	604	-
6035000	Q(STATION)	221	346	438	567	671	782	813
	Q(PREDICTED)	202	337	439	578	689	805	-
	Q(WEIGHTED)	220	345	438	569	675	787	-
6036600	Q(STATION)	2	5	7	12	16	22	10
	Q(PREDICTED)	1	7	15	40	74	129	-
	Q(WEIGHTED)	2	6	10	24	40	65	-
6037500	Q(STATION)	1320	1620	1800	2000	2140	2270	2150
	Q(PREDICTED)	940	1240	1440	1640	1800	1940	-
	Q(WEIGHTED)	1300	1580	1750	1940	2090	2220	-
6055500	Q(STATION)	514	743	906	1120	1300	1470	1300
	Q(PREDICTED)	193	304	384	489	569	652	-
	Q(WEIGHTED)	469	623	723	873	1030	1170	-
6056200	Q(STATION)	20	31	38	49	58	67	47
	Q(PREDICTED)	8	17	24	37	48	60	-
	Q(WEIGHTED)	18	27	33	44	54	64	-

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES						
		SOUTHWEST REGION--Continued						
6056300	Q(STATION)	14	37	62	106	150	205	70
	Q(PREDICTED)	33	74	111	174	231	299	-
	Q(WEIGHTED)	17	47	79	132	179	238	-
6056600	Q(STATION)	206	326	418	550	658	776	445
	Q(PREDICTED)	207	361	481	650	787	935	-
	Q(WEIGHTED)	206	336	442	592	709	838	-
6058700	Q(STATION)	16	56	109	220	347	522	139
	Q(PREDICTED)	19	63	114	221	337	497	-
	Q(WEIGHTED)	16	58	111	220	344	514	-
6061500	Q(STATION)	264	414	522	664	775	890	1200
	Q(PREDICTED)	323	628	891	1290	1630	2020	-
	Q(WEIGHTED)	268	444	593	802	948	1120	-
6061700	Q(STATION)	12	19	25	33	39	47	25
	Q(PREDICTED)	8	18	27	43	57	74	-
	Q(WEIGHTED)	11	19	26	37	46	58	-
6061800	Q(STATION)	12	26	40	64	86	112	80
	Q(PREDICTED)	9	24	38	65	91	123	-
	Q(WEIGHTED)	12	25	39	64	88	116	-
6061900	Q(STATION)	149	261	350	480	587	705	390
	Q(PREDICTED)	73	149	213	316	406	508	-
	Q(WEIGHTED)	137	228	298	411	516	628	-
6062500	Q(STATION)	223	373	480	619	725	831	995
	Q(PREDICTED)	108	183	237	314	375	440	-
	Q(WEIGHTED)	218	355	448	572	676	777	-
6062700	Q(STATION)	2	5	7	11	14	18	16
	Q(PREDICTED)	2	4	6	10	14	19	-
	Q(WEIGHTED)	2	5	7	11	15	18	-
6063000	Q(STATION)	259	484	663	919	1130	1350	1360
	Q(PREDICTED)	229	448	637	923	1170	1450	-
	Q(WEIGHTED)	257	479	659	920	1140	1370	-
6068500	Q(STATION)	145	258	348	479	589	709	454
	Q(PREDICTED)	109	207	286	407	509	622	-
	Q(WEIGHTED)	140	245	328	453	562	680	-
6071200	Q(STATION)	99	235	367	593	808	1070	580
	Q(PREDICTED)	65	187	321	581	849	1200	-
	Q(WEIGHTED)	94	221	350	588	824	1120	-
6071400	Q(STATION)	73	229	415	784	1180	1710	1160
	Q(PREDICTED)	26	107	221	493	824	1320	-
	Q(WEIGHTED)	66	193	342	662	1040	1560	-
6071600	Q(STATION)	110	282	460	776	1090	1470	1020
	Q(PREDICTED)	57	197	376	764	1200	1820	-
	Q(WEIGHTED)	103	260	432	771	1130	1590	-
		UPPER YELLOWSTONE-CENTRAL MOUNTAIN REGION						
6043000	Q(STATION)	777	926	1010	1120	1190	1250	1020
	Q(PREDICTED)	622	887	1070	1310	1500	1690	-
	Q(WEIGHTED)	755	916	1030	1210	1350	1480	-
6043200	Q(STATION)	266	397	490	613	709	808	690
	Q(PREDICTED)	187	290	366	471	555	644	-
	Q(WEIGHTED)	258	377	455	563	647	739	-
6043300	Q(STATION)	15	24	30	38	44	51	30
	Q(PREDICTED)	17	31	43	61	77	95	-
	Q(WEIGHTED)	15	25	33	45	56	68	-
6043500	Q(STATION)	5310	7060	8120	9370	10200	11100	10000
	Q(PREDICTED)	3900	5090	5870	6840	7550	8240	-
	Q(WEIGHTED)	5270	6960	7920	9070	9820	10700	-

Table 1.--*Annual flood magnitude-frequency data for streamflow-gaging stations*--Continued

STATION		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES						
		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
		UPPER YELLOWSTONE-CENTRAL MOUNTAIN REGION--Continued						
6046500	Q(STATION)	374	598	768	1010	1200	1420	1230
	Q(PREDICTED)	153	270	367	513	638	780	-
	Q(WEIGHTED)	357	550	675	862	1010	1190	-
6046700	Q(STATION)	13	31	49	81	112	150	70
	Q(PREDICTED)	19	46	75	128	181	250	-
	Q(WEIGHTED)	14	34	57	98	141	194	-
6047000	Q(STATION)	146	234	302	396	474	557	370
	Q(PREDICTED)	68	115	152	206	252	302	-
	Q(WEIGHTED)	139	213	262	331	387	453	-
6048000	Q(STATION)	542	823	1030	1310	1540	1780	1240
	Q(PREDICTED)	450	757	1000	1350	1650	1980	-
	Q(WEIGHTED)	535	813	1020	1320	1580	1850	-
6048500	Q(STATION)	288	459	590	774	925	1090	902
	Q(PREDICTED)	255	430	568	769	938	1120	-
	Q(WEIGHTED)	286	455	585	773	929	1100	-
6050000	Q(STATION)	367	525	634	778	889	1000	956
	Q(PREDICTED)	252	384	480	610	713	824	-
	Q(WEIGHTED)	357	501	594	723	822	930	-
6052500	Q(STATION)	4870	6570	7670	9030	10000	11000	9840
	Q(PREDICTED)	4950	6900	8240	10000	11300	12700	-
	Q(WEIGHTED)	4870	6590	7730	9160	10200	11300	-
6074500	Q(STATION)	121	265	407	652	892	1190	770
	Q(PREDICTED)	116	194	254	341	414	494	-
	Q(WEIGHTED)	120	248	353	516	657	836	-
6075600	Q(STATION)	13	25	35	52	66	84	52
	Q(PREDICTED)	26	52	76	115	151	195	-
	Q(WEIGHTED)	14	30	48	76	103	134	-
6076000	Q(STATION)	13	26	39	60	81	106	56
	Q(PREDICTED)	28	50	70	100	125	154	-
	Q(WEIGHTED)	14	30	46	72	96	123	-
6076700	Q(STATION)	59	96	123	161	191	223	138
	Q(PREDICTED)	35	60	80	110	136	164	-
	Q(WEIGHTED)	57	90	112	144	170	200	-
6076800	Q(STATION)	9	15	21	30	38	47	37
	Q(PREDICTED)	11	21	29	42	52	65	-
	Q(WEIGHTED)	9	17	24	35	44	55	-
6077000	Q(STATION)	208	303	372	467	542	622	460
	Q(PREDICTED)	210	330	421	546	649	757	-
	Q(WEIGHTED)	208	306	380	485	570	660	-
6077500	Q(STATION)	1940	3330	4470	6170	7640	9280	12300
	Q(PREDICTED)	3550	5640	7240	9510	11400	13400	-
	Q(WEIGHTED)	2070	3700	5160	7230	9020	10900	-
6077700	Q(STATION)	3	11	25	60	107	182	80
	Q(PREDICTED)	5	16	31	63	100	154	-
	Q(WEIGHTED)	3	12	27	61	104	169	-
6077800	Q(STATION)	83	242	422	764	1120	1580	1340
	Q(PREDICTED)	64	179	316	585	879	1280	-
	Q(WEIGHTED)	81	232	396	707	1030	1470	-
6090500	Q(STATION)	1530	2550	3400	4690	5820	7120	11000
	Q(PREDICTED)	1470	2330	2990	3910	4670	5480	-
	Q(WEIGHTED)	1530	2520	3320	4490	5470	6600	-
6109800	Q(STATION)	232	455	647	944	1210	1500	1340
	Q(PREDICTED)	343	543	695	906	1080	1260	-
	Q(WEIGHTED)	241	469	659	932	1160	1410	-
6115500	Q(STATION)	85	155	212	293	362	437	423
	Q(PREDICTED)	93	161	216	296	357	443	-
	Q(WEIGHTED)	86	156	213	294	361	438	-

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
	DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES							
	UPPER YELLOWSTONE-CENTRAL MOUNTAIN REGION--Continued							
6117000	Q(STATION)	49	104	153	232	304	387	167
	Q(PREDICTED)	75	130	175	240	296	359	-
	Q(WEIGHTED)	53	111	162	236	300	371	-
6118500	Q(STATION)	737	1220	1620	2210	2730	3300	5240
	Q(PREDICTED)	678	1080	1390	1830	2190	2580	-
	Q(WEIGHTED)	734	1210	1590	2130	2600	3120	-
6120500	Q(STATION)	1060	2040	2790	3820	4630	5470	7270
	Q(PREDICTED)	2190	3550	4600	6090	7340	8710	-
	Q(WEIGHTED)	1090	2120	2950	4090	5020	5960	-
6122000	Q(STATION)	328	727	1100	1690	2240	2870	2050
	Q(PREDICTED)	752	1420	2010	2940	3770	4730	-
	Q(WEIGHTED)	360	829	1310	2060	2770	3540	-
6187500	Q(STATION)	310	467	578	728	845	967	642
	Q(PREDICTED)	394	568	713	891	1030	1180	-
	Q(WEIGHTED)	317	482	610	778	911	1050	-
6188000	Q(STATION)	8400	10500	11700	13200	14300	15300	13600
	Q(PREDICTED)	2790	3800	4480	5350	6000	6650	-
	Q(WEIGHTED)	8190	10000	10800	11900	12700	13500	-
6191000	Q(STATION)	1120	1510	1760	2060	2270	2480	2080
	Q(PREDICTED)	1240	1670	2060	2510	2840	3180	-
	Q(WEIGHTED)	1120	1520	1790	2130	2380	2620	-
6191500	Q(STATION)	17400	22000	24700	27800	29800	31800	32000
	Q(PREDICTED)	15000	18100	20000	22200	23800	25200	-
	Q(WEIGHTED)	17300	21800	24300	27200	29000	30800	-
6193000	Q(STATION)	553	852	1080	1400	1660	1940	1770
	Q(PREDICTED)	475	721	899	1150	1340	1550	-
	Q(WEIGHTED)	547	833	1040	1330	1550	1800	-
6193500	Q(STATION)	1060	1800	2390	3250	3970	4770	4500
	Q(PREDICTED)	2010	3250	4210	5560	6680	7910	-
	Q(WEIGHTED)	1100	1920	2640	3680	4570	5500	-
6194000	Q(STATION)	211	392	548	791	1010	1260	1400
	Q(PREDICTED)	214	371	498	685	845	1030	-
	Q(WEIGHTED)	211	389	538	764	960	1190	-
6197000	Q(STATION)	674	1220	1710	2510	3260	4150	5870
	Q(PREDICTED)	423	705	927	1250	1520	1810	-
	Q(WEIGHTED)	643	1100	1450	1980	2440	3010	-
6197500	Q(STATION)	3740	4570	5090	5740	6210	6680	6800
	Q(PREDICTED)	2370	3260	3850	4620	5200	5790	-
	Q(WEIGHTED)	3670	4430	4880	5490	5940	6430	-
6200000	Q(STATION)	5950	7400	8330	9490	10300	11200	9840
	Q(PREDICTED)	3190	4490	5380	6550	7430	8340	-
	Q(WEIGHTED)	5800	7080	7810	8810	9520	10400	-
6200500	Q(STATION)	945	1370	1700	2150	2510	2910	3510
	Q(PREDICTED)	587	916	1160	1500	1770	2070	-
	Q(WEIGHTED)	932	1340	1630	2040	2360	2730	-
6201000	Q(STATION)	950	1540	2010	2700	3270	3910	3000
	Q(PREDICTED)	857	1530	2090	2940	3690	4530	-
	Q(WEIGHTED)	945	1540	2020	2760	3390	4090	-
6201550	Q(STATION)	9	24	40	69	101	142	55
	Q(PREDICTED)	17	51	94	184	285	427	-
	Q(WEIGHTED)	10	29	57	113	181	271	-
6201600	Q(STATION)	140	564	1200	2740	4720	7770	2680
	Q(PREDICTED)	319	690	1050	1660	2230	2940	-
	Q(WEIGHTED)	158	588	1160	2340	3670	5660	-
6201650	Q(STATION)	104	395	807	1750	2900	4580	3200
	Q(PREDICTED)	197	520	881	1570	2300	3270	-
	Q(WEIGHTED)	113	419	829	1680	2650	4010	-

Table 1.--*Annual flood magnitude-frequency data for streamflow-gaging stations*--Continued

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES						
		UPPER YELLOWSTONE-CENTRAL MOUNTAIN REGION--Continued						
6201700	Q(STATION)	40	123	228	447	696	1040	307
	Q(PREDICTED)	46	133	237	445	673	986	-
	Q(WEIGHTED)	41	125	230	446	687	1020	-
6204050	Q(STATION)	747	1240	1620	2180	2640	3160	1630
	Q(PREDICTED)	767	1360	1630	1980	2240	2520	-
	Q(WEIGHTED)	749	1270	1620	2100	2450	2850	-
6204500	Q(STATION)	2310	3250	3910	4780	5460	6160	5790
	Q(PREDICTED)	2840	4070	4930	6070	6930	7830	-
	Q(WEIGHTED)	2340	3330	4070	5050	5830	6600	-
6205000	Q(STATION)	6600	8490	9710	11300	12400	13500	12000
	Q(PREDICTED)	5150	7460	9100	11300	13000	14800	-
	Q(WEIGHTED)	6550	8410	9640	11300	12500	13800	-
6205100	Q(STATION)	86	246	436	811	1220	1780	1580
	Q(PREDICTED)	36	108	196	377	579	861	-
	Q(WEIGHTED)	81	222	372	663	969	1410	-
6206500	Q(STATION)	1150	1480	1720	2050	2320	2600	4000
	Q(PREDICTED)	887	1240	1470	1780	2010	2250	-
	Q(WEIGHTED)	1140	1450	1670	1990	2230	2500	-
6207500	Q(STATION)	7640	9160	10100	11100	11900	12600	12700
	Q(PREDICTED)	5050	6790	7960	9440	10500	11600	-
	Q(WEIGHTED)	7560	9010	9880	10900	11700	12400	-
6207800	Q(STATION)	110	313	550	1020	1520	2200	2650
	Q(PREDICTED)	186	489	824	1460	2130	3010	-
	Q(WEIGHTED)	121	358	653	1220	1830	2630	-
6208500	Q(STATION)	7780	9540	10600	11800	12700	13500	11800
	Q(PREDICTED)	4580	6870	8570	10900	12700	14600	-
	Q(WEIGHTED)	7680	9370	10400	11700	12700	13700	-
6209500	Q(STATION)	1210	1710	2060	2510	2860	3210	3110
	Q(PREDICTED)	1300	1750	2050	2440	2720	3010	-
	Q(WEIGHTED)	1210	1710	2060	2500	2830	3170	-
6210000	Q(STATION)	528	798	995	1260	1480	1700	1850
	Q(PREDICTED)	582	826	993	1210	1380	1550	-
	Q(WEIGHTED)	532	802	995	1250	1450	1650	-
6211000	Q(STATION)	574	1200	1780	2720	3580	4600	2260
	Q(PREDICTED)	794	1510	2130	3110	3980	5000	-
	Q(WEIGHTED)	583	1230	1830	2790	3670	4690	-
6211500	Q(STATION)	250	563	879	1440	1990	2700	1720
	Q(PREDICTED)	261	610	964	1600	2220	3010	-
	Q(WEIGHTED)	250	567	891	1470	2040	2770	-
6215000	Q(STATION)	140	281	400	577	727	893	575
	Q(PREDICTED)	162	296	409	583	735	910	-
	Q(WEIGHTED)	143	285	403	580	731	902	-
6216000	Q(STATION)	177	331	468	686	884	1120	2280
	Q(PREDICTED)	252	463	644	923	1170	1450	-
	Q(WEIGHTED)	186	359	524	781	1010	1270	-
6216200	Q(STATION)	121	228	320	464	591	738	565
	Q(PREDICTED)	28	82	148	282	433	640	-
	Q(WEIGHTED)	115	208	283	413	540	705	-
6216300	Q(STATION)	80	197	321	551	786	1090	924
	Q(PREDICTED)	8	25	48	95	150	229	-
	Q(WEIGHTED)	74	170	253	406	553	760	-
6216500	Q(STATION)	651	1300	1920	3010	4090	5440	14900
	Q(PREDICTED)	865	1780	2640	4050	5370	6950	-
	Q(WEIGHTED)	659	1330	2010	3180	4340	5740	-
6287500	Q(STATION)	408	941	1530	2660	3880	5530	7810
	Q(PREDICTED)	337	647	1320	2220	3130	4300	-
	Q(WEIGHTED)	403	898	1480	2530	3620	5090	-

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
	DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES							
	UPPER YELLOWSTONE-CENTRAL MOUNTAIN REGION--Continued							
6288200	Q(STATION)	571	1170	1740	2670	3550	4600	7350
	Q(PREDICTED)	288	741	1240	2180	3160	4450	-
	Q(WEIGHTED)	531	1060	1550	2450	3350	4520	-
6289000	Q(STATION)	1080	1520	1800	2150	2420	2670	2730
	Q(PREDICTED)	929	1320	1580	1940	2210	2490	-
	Q(WEIGHTED)	1070	1500	1770	2110	2370	2630	-
6290000	Q(STATION)	316	615	906	1420	1920	2570	5560
	Q(PREDICTED)	578	1170	1720	2610	3440	4430	-
	Q(WEIGHTED)	336	697	1090	1770	2440	3240	-
6290500	Q(STATION)	1310	2130	2820	3890	4830	5920	8010
	Q(PREDICTED)	1620	2620	3400	4490	5400	6380	-
	Q(WEIGHTED)	1320	2170	2910	4010	4960	6030	-
6291500	Q(STATION)	440	634	773	961	1110	1270	1130
	Q(PREDICTED)	361	619	828	1140	1390	1680	-
	Q(WEIGHTED)	436	633	781	997	1180	1370	-
6294000	Q(STATION)	2050	3750	5160	7250	9040	11000	22600
	Q(PREDICTED)	2100	3850	5360	7660	9710	12000	-
	Q(WEIGHTED)	2050	3760	5200	7360	9250	11300	-
6298000	Q(STATION)	1670	2270	2660	3140	3490	3840	3400
	Q(PREDICTED)	1570	2180	2600	3130	3540	3960	-
	Q(WEIGHTED)	1670	2260	2650	3140	3500	3860	-
6298500	Q(STATION)	123	228	316	451	568	701	850
	Q(PREDICTED)	187	303	392	518	621	733	-
	Q(WEIGHTED)	128	239	333	470	586	712	-
6299500	Q(STATION)	314	498	638	837	1000	1180	1130
	Q(PREDICTED)	270	420	531	684	809	942	-
	Q(WEIGHTED)	312	490	621	805	952	1120	-
6300500	Q(STATION)	527	706	824	974	1090	1200	1230
	Q(PREDICTED)	337	497	610	762	881	1000	-
	Q(WEIGHTED)	514	678	779	917	1020	1130	-
	NORTHWEST-FOOTHILLS REGION							
6087900	Q(STATION)	144	301	443	669	874	1120	620
	Q(PREDICTED)	33	115	176	352	552	826	-
	Q(WEIGHTED)	114	210	262	425	622	900	-
6088500	Q(STATION)	637	1230	1780	2760	3690	4890	7600
	Q(PREDICTED)	358	1000	1380	2520	3720	5320	-
	Q(WEIGHTED)	613	1180	1640	2640	3710	5090	-
6089300	Q(STATION)	72	193	322	556	793	1100	530
	Q(PREDICTED)	68	220	366	713	1100	1630	-
	Q(WEIGHTED)	71	201	344	656	999	1430	-
6099700	Q(STATION)	91	349	701	1480	2400	3690	4240
	Q(PREDICTED)	147	452	1020	1920	2880	4170	-
	Q(WEIGHTED)	99	385	873	1790	2750	4030	-
6100200	Q(STATION)	6	27	60	144	250	414	249
	Q(PREDICTED)	15	56	110	228	364	553	-
	Q(WEIGHTED)	7	35	85	199	330	508	-
6100300	Q(STATION)	56	249	543	1260	2150	3470	5440
	Q(PREDICTED)	75	242	449	869	1330	1960	-
	Q(WEIGHTED)	58	246	491	980	1530	2360	-
6101600	Q(STATION)	8	18	28	44	59	77	38
	Q(PREDICTED)	4	18	37	82	136	214	-
	Q(WEIGHTED)	8	18	33	69	110	159	-
6101700	Q(STATION)	29	97	184	366	568	848	675
	Q(PREDICTED)	18	66	129	266	426	650	-
	Q(WEIGHTED)	26	83	150	929	459	702	-

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
	DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES							
			NORTHWEST-FOOTHILLS REGION--Continued					
6101800	Q(STATION)	7	47	132	404	833	1610	220
	Q(PREDICTED)	51	170	320	634	989	1480	-
	Q(WEIGHTED)	9	77	220	558	947	1510	-
6101900	Q(STATION)	8	49	123	329	624	1120	369
	Q(PREDICTED)	21	75	233	476	759	1150	-
	Q(WEIGHTED)	9	57	178	429	722	1140	-
6102100	Q(STATION)	19	64	123	247	390	589	244
	Q(PREDICTED)	6	25	82	178	293	459	-
	Q(WEIGHTED)	15	44	97	195	315	492	-
6102200	Q(STATION)	17	56	113	232	368	558	300
	Q(PREDICTED)	10	36	104	221	361	561	-
	Q(WEIGHTED)	15	48	108	224	362	560	-
6102300	Q(STATION)	3	11	21	40	60	88	42
	Q(PREDICTED)	3	14	37	83	138	220	-
	Q(WEIGHTED)	3	12	29	66	110	166	-
6105800	Q(STATION)	68	164	258	417	571	759	390
	Q(PREDICTED)	31	108	186	296	462	871	-
	Q(WEIGHTED)	60	140	214	327	489	837	-
6108200	Q(STATION)	23	186	547	1730	3650	7130	2070
	Q(PREDICTED)	53	177	526	1040	1610	2380	-
	Q(WEIGHTED)	27	182	535	1200	1990	3270	-
6108300	Q(STATION)	16	82	199	508	936	1620	460
	Q(PREDICTED)	29	100	308	619	975	1470	-
	Q(WEIGHTED)	17	88	256	586	965	1510	-
6132400	Q(STATION)	217	701	1300	2500	3810	5580	2200
	Q(PREDICTED)	190	573	1280	2380	3530	5050	-
	Q(WEIGHTED)	212	651	1290	2410	3610	5200	-
6133000	Q(STATION)	1060	2290	3420	5270	6930	8880	7930
	Q(PREDICTED)	817	2160	2870	5020	7210	10000	-
	Q(WEIGHTED)	1030	2260	3240	5150	7070	9390	-
6133500	Q(STATION)	293	753	1240	2100	2960	4030	3090
	Q(PREDICTED)	309	891	1550	2820	4160	5900	-
	Q(WEIGHTED)	293	778	1330	2430	3550	4880	-
6134500	Q(STATION)	1950	3570	4940	7060	8950	11200	9170
	Q(PREDICTED)	755	1990	2650	4680	6790	9530	-
	Q(WEIGHTED)	1870	3310	4260	6070	8000	10500	-
6134800	Q(STATION)	32	81	136	239	349	493	239
	Q(PREDICTED)	52	173	230	453	703	1050	-
	Q(WEIGHTED)	34	107	182	375	585	841	-
			NORTHEAST PLAINS REGION					
6109900	Q(STATION)	17	51	91	171	256	369	125
	Q(PREDICTED)	32	80	130	219	308	418	-
	Q(WEIGHTED)	19	62	111	200	288	399	-
6110000	Q(STATION)	469	815	1070	1400	1640	1890	1750
	Q(PREDICTED)	434	845	1210	1800	2330	2940	-
	Q(WEIGHTED)	466	820	1100	1510	1830	2170	-
6111700	Q(STATION)	15	36	57	95	134	182	87
	Q(PREDICTED)	17	46	79	141	206	287	-
	Q(WEIGHTED)	15	39	67	119	171	236	-
6112100	Q(STATION)	327	768	1220	2000	2770	3730	1740
	Q(PREDICTED)	122	274	423	678	925	1220	-
	Q(WEIGHTED)	255	496	686	1040	1420	1910	-
6128400	Q(STATION)	250	670	1130	1960	2810	3880	2200
	Q(PREDICTED)	113	321	550	973	1400	1940	-
	Q(WEIGHTED)	201	479	746	1250	1800	2500	-

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
	DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES							
	NORTHEAST PLAINS REGION--Continued							
6128500	Q(STATION)	66	116	156	214	262	314	185
	Q(PREDICTED)	24	75	136	254	380	543	-
	Q(WEIGHTED)	51	96	144	237	328	436	-
6129100	Q(STATION)	12	27	43	72	101	136	60
	Q(PREDICTED)	14	38	65	116	169	237	-
	Q(WEIGHTED)	12	31	53	96	139	191	-
6129200	Q(STATION)	25	102	217	494	844	1380	757
	Q(PREDICTED)	26	73	125	222	322	449	-
	Q(WEIGHTED)	25	87	158	296	457	677	-
6129400	Q(STATION)	14	36	61	105	152	210	141
	Q(PREDICTED)	8	27	49	95	145	211	-
	Q(WEIGHTED)	11	31	54	98	147	210	-
6129500	Q(STATION)	347	691	987	1450	1840	2260	1590
	Q(PREDICTED)	385	918	1440	2310	3130	4100	-
	Q(WEIGHTED)	351	744	1130	1760	2300	2900	-
6135500	Q(STATION)	614	1210	1670	2320	2840	3390	3500
	Q(PREDICTED)	291	753	1200	1910	2550	3270	-
	Q(WEIGHTED)	557	1070	1480	2140	2710	3340	-
6137900	Q(STATION)	13	40	74	141	214	312	299
	Q(PREDICTED)	12	42	77	145	216	308	-
	Q(WEIGHTED)	12	40	75	143	215	309	-
6138700	Q(STATION)	16	71	157	363	619	999	190
	Q(PREDICTED)	40	126	225	410	601	841	-
	Q(WEIGHTED)	19	88	188	389	609	905	-
6138800	Q(STATION)	35	139	286	610	994	1530	345
	Q(PREDICTED)	78	234	408	726	1050	1440	-
	Q(WEIGHTED)	43	175	350	682	1030	1470	-
6139500	Q(STATION)	373	1210	2200	4100	6120	8720	5570
	Q(PREDICTED)	1280	3140	4910	7760	10300	13200	-
	Q(WEIGHTED)	482	1720	3240	5850	8170	11000	-
6140400	Q(STATION)	104	276	457	770	1080	1450	700
	Q(PREDICTED)	102	293	501	875	1250	1700	-
	Q(WEIGHTED)	103	284	481	835	1180	1600	-
6141900	Q(STATION)	1	8	19	49	91	155	72
	Q(PREDICTED)	2	8	17	35	56	84	-
	Q(WEIGHTED)	1	7	17	39	66	105	-
6144350	Q(STATION)	403	931	1420	2180	2840	3590	4980
	Q(PREDICTED)	292	679	1020	1550	2000	2490	-
	Q(WEIGHTED)	368	806	1170	1750	2270	2850	-
6144500	Q(STATION)	1330	2770	3970	5680	7080	8560	5110
	Q(PREDICTED)	991	2330	3520	5350	6900	8630	-
	Q(WEIGHTED)	1280	2660	3820	5550	7000	8580	-
6145000	Q(STATION)	308	632	904	1320	1660	2020	1160
	Q(PREDICTED)	171	483	802	1340	1840	2420	-
	Q(WEIGHTED)	270	569	851	1330	1750	2240	-
6148000	Q(STATION)	552	1120	1570	2220	2750	3320	3020
	Q(PREDICTED)	439	1000	1500	2280	2950	3690	-
	Q(WEIGHTED)	530	1080	1540	2240	2840	3490	-
6150000	Q(STATION)	383	1050	1670	2660	3540	4510	3090
	Q(PREDICTED)	175	490	811	1350	1850	2430	-
	Q(WEIGHTED)	351	880	1330	2060	2770	3590	-
6150500	Q(STATION)	342	813	1230	1820	2310	2820	2300
	Q(PREDICTED)	204	557	910	1500	2030	2650	-
	Q(WEIGHTED)	322	747	1110	1690	2200	2760	-
6151000	Q(STATION)	222	521	779	1170	1480	1820	1220
	Q(PREDICTED)	150	415	682	1130	1540	2020	-
	Q(WEIGHTED)	211	495	748	1150	1500	1880	-

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
	DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES							
	NORTHEAST PLAINS REGION--Continued							
6154400	Q(STATION)	388	1240	2210	4000	5830	8110	8460
	Q(PREDICTED)	452	1150	1820	2960	4000	5220	-
	Q(WEIGHTED)	407	1190	1960	3250	4500	6010	-
6154500	Q(STATION)	879	2000	2970	4470	5770	7200	3940
	Q(PREDICTED)	771	1870	2900	4550	6010	7690	-
	Q(WEIGHTED)	855	1940	2930	4510	5900	7470	3940
6155100	Q(STATION)	75	145	201	280	343	411	220
	Q(PREDICTED)	28	93	169	310	455	634	-
	Q(WEIGHTED)	54	115	180	300	416	552	-
6155200	Q(STATION)	136	557	1120	2250	3460	5030	800
	Q(PREDICTED)	225	665	1120	1900	2620	3480	-
	Q(WEIGHTED)	153	600	1120	2030	2920	4030	-
6155300	Q(STATION)	30	92	159	279	395	536	360
	Q(PREDICTED)	23	78	142	262	385	536	-
	Q(WEIGHTED)	28	86	150	270	389	535	-
6155400	Q(STATION)	9	43	92	201	322	485	105
	Q(PREDICTED)	20	68	124	230	338	472	-
	Q(WEIGHTED)	11	52	108	217	331	477	-
6156000	Q(STATION)	166	941	2130	4740	7670	11600	3500
	Q(PREDICTED)	867	2260	3560	5620	7400	9380	-
	Q(WEIGHTED)	194	1120	2450	5020	7570	10700	-
6158000	Q(STATION)	1500	2750	3690	5000	6030	7090	12600
	Q(PREDICTED)	897	2000	2910	4220	5270	6380	-
	Q(WEIGHTED)	1390	2520	3380	4640	5680	6770	-
6168500	Q(STATION)	584	1370	2030	3040	3880	4770	3310
	Q(PREDICTED)	776	1950	2990	4530	5790	7140	-
	Q(WEIGHTED)	606	1500	2340	3600	4600	5650	-
6169000	Q(STATION)	284	753	1190	1820	2370	2950	1800
	Q(PREDICTED)	351	942	1490	2340	3070	3850	-
	Q(WEIGHTED)	291	789	1270	2000	2600	3240	-
6169500	Q(STATION)	1080	2420	3550	5180	6500	7890	5110
	Q(PREDICTED)	942	2360	3590	5420	6900	8470	-
	Q(WEIGHTED)	1050	2390	3560	5280	6670	8140	-
6170000	Q(STATION)	635	2330	4000	6460	8400	10400	7080
	Q(PREDICTED)	637	1640	2540	3900	5020	6240	-
	Q(WEIGHTED)	634	2170	3530	5460	7080	8740	-
6178000	Q(STATION)	819	2230	3650	6100	8400	11200	12700
	Q(PREDICTED)	1020	2510	3790	5680	7210	8810	-
	Q(WEIGHTED)	837	2280	3690	5940	7950	10200	-
6178500	Q(STATION)	702	1860	2900	4470	5770	7170	4020
	Q(PREDICTED)	1280	3160	4800	7180	9100	11100	-
	Q(WEIGHTED)	751	2090	3390	5350	6860	8440	-
6179500	Q(STATION)	219	960	1950	3920	6030	8700	5450
	Q(PREDICTED)	551	1400	2160	3300	4250	5260	-
	Q(WEIGHTED)	267	1110	2050	3550	4940	6550	-
6180000	Q(STATION)	589	1500	2330	3620	4740	5960	3600
	Q(PREDICTED)	473	1290	2120	3540	4850	6430	-
	Q(WEIGHTED)	554	1400	2210	3570	4810	6250	-
6182500	Q(STATION)	1040	2590	4000	6180	8060	10200	6360
	Q(PREDICTED)	628	1710	2720	4310	5660	7130	-
	Q(WEIGHTED)	941	2250	3370	5130	6720	8460	-
6183000	Q(STATION)	1130	2550	3790	5600	7100	8700	8000
	Q(PREDICTED)	182	1900	2960	4570	5900	7330	-
	Q(WEIGHTED)	740	2270	3330	4970	6370	7880	-
6183100	Q(STATION)	93	173	233	314	376	437	328
	Q(PREDICTED)	38	121	209	363	507	676	-
	Q(WEIGHTED)	75	149	220	341	447	562	-

Table 1.--*Annual flood magnitude-frequency data for streamflow-gaging stations*--Continued

STATION		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
				NORTHEAST PLAINS REGION--Continued				
6183300	Q(STATION)	30	65	95	140	176	213	240
	Q(PREDICTED)	32	101	176	306	430	573	-
	Q(WEIGHTED)	30	76	126	210	280	354	-
6183400	Q(STATION)	85	366	740	1500	2290	3300	690
	Q(PREDICTED)	55	172	296	508	705	933	-
	Q(WEIGHTED)	76	271	463	797	1150	1590	-
6329700	Q(STATION)	8	31	57	105	152	210	110
	Q(PREDICTED)	6	23	44	87	132	191	-
	Q(WEIGHTED)	8	27	50	94	140	198	-
6329800	Q(STATION)	95	254	406	649	864	1110	1200
	Q(PREDICTED)	72	236	416	736	1050	1420	-
	Q(WEIGHTED)	88	246	411	698	966	1270	-
6329900	Q(STATION)	30	103	186	336	481	655	276
	Q(PREDICTED)	45	152	273	492	708	968	-
	Q(WEIGHTED)	32	119	226	419	601	820	-
6330100	Q(STATION)	135	456	815	1460	2080	2810	1250
	Q(PREDICTED)	117	383	673	1180	1670	2240	-
	Q(WEIGHTED)	130	425	739	1290	1830	2470	-
6331000	Q(STATION)	1230	2810	4160	6150	7810	9580	6910
	Q(PREDICTED)	832	2420	3980	6520	8750	11300	-
	Q(WEIGHTED)	1130	2660	4070	6330	8280	10400	-
6331900	Q(STATION)	72	193	310	498	663	849	1120
	Q(PREDICTED)	61	193	336	581	811	1080	-
	Q(WEIGHTED)	68	193	324	550	756	991	-
				EAST-CENTRAL PLAINS REGION				
6115100	Q(STATION)	47	305	798	2190	4160	7380	1950
	Q(PREDICTED)	84	294	546	1030	1530	2130	-
	Q(WEIGHTED)	55	301	692	1660	3020	5120	-
6115300	Q(STATION)	61	220	423	838	1290	1900	470
	Q(PREDICTED)	53	188	356	685	1050	1490	-
	Q(WEIGHTED)	59	208	395	769	1190	1720	-
6120600	Q(STATION)	1	6	13	30	52	84	68
	Q(PREDICTED)	8	31	66	145	244	394	-
	Q(WEIGHTED)	3	14	34	79	130	209	-
6120700	Q(STATION)	42	113	188	320	449	608	307
	Q(PREDICTED)	18	68	138	296	486	764	-
	Q(WEIGHTED)	37	98	168	310	464	671	-
6120800	Q(STATION)	77	420	1060	2900	5630	10300	5390
	Q(PREDICTED)	67	227	432	855	1340	1990	-
	Q(WEIGHTED)	75	365	849	2150	4140	7440	-
6120900	Q(STATION)	115	695	1760	4730	8910	15700	24400
	Q(PREDICTED)	168	542	1010	1960	3050	4480	-
	Q(WEIGHTED)	124	650	1500	3690	6820	11700	-
6125700	Q(STATION)	115	388	717	1360	2030	2910	2400
	Q(PREDICTED)	204	626	1120	2070	3120	4400	-
	Q(WEIGHTED)	136	478	893	1690	2520	3580	-
6126300	Q(STATION)	138	437	788	1460	2170	3090	1620
	Q(PREDICTED)	175	539	966	1790	2700	3810	-
	Q(WEIGHTED)	147	476	866	1620	2410	3410	-
6127100	Q(STATION)	66	189	326	575	826	1140	510
	Q(PREDICTED)	18	69	134	271	427	632	-
	Q(WEIGHTED)	55	144	242	432	647	913	-
6127200	Q(STATION)	48	115	182	300	414	554	380
	Q(PREDICTED)	47	160	297	564	855	1210	-
	Q(WEIGHTED)	48	132	232	424	612	847	-

Table 1.--*Annual flood magnitude-frequency data for streamflow-gaging stations*--Continued

STATION		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES						
		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
		EAST-CENTRAL PLAINS REGION--Continued						
6127570	Q(STATION)	99	228	352	557	750	980	488
	Q(PREDICTED)	42	143	265	500	751	1060	-
	Q(WEIGHTED)	86	197	315	531	750	1010	-
6128900	Q(STATION)	123	279	426	669	894	1160	1030
	Q(PREDICTED)	90	300	542	995	1480	2030	-
	Q(WEIGHTED)	117	286	470	803	1120	1500	-
6129000	Q(STATION)	1270	3050	4710	7350	9700	12400	9910
	Q(PREDICTED)	567	1640	2790	4860	7050	9440	-
	Q(WEIGHTED)	1150	2620	4030	6380	8730	11300	-
6129700	Q(STATION)	73	253	481	951	1470	2180	60
	Q(PREDICTED)	30	108	204	392	596	845	-
	Q(WEIGHTED)	64	200	365	697	1090	1610	-
6129800	Q(STATION)	40	125	224	418	624	893	380
	Q(PREDICTED)	17	63	121	238	366	528	-
	Q(WEIGHTED)	36	108	190	354	537	771	-
6130600	Q(STATION)	78	212	356	616	876	1200	748
	Q(PREDICTED)	145	465	826	1490	2180	2950	-
	Q(WEIGHTED)	93	304	554	1010	1440	1950	-
6130800	Q(STATION)	17	66	129	255	392	571	334
	Q(PREDICTED)	14	52	100	198	305	442	-
	Q(WEIGHTED)	17	61	117	230	356	517	-
6130850	Q(STATION)	42	129	225	399	571	782	760
	Q(PREDICTED)	30	106	200	384	582	824	-
	Q(WEIGHTED)	40	122	216	393	575	797	-
6130900	Q(STATION)	13	53	106	214	332	489	458
	Q(PREDICTED)	17	63	121	236	361	519	-
	Q(WEIGHTED)	14	57	113	224	345	502	-
6130950	Q(STATION)	1780	3660	5210	7470	9330	11300	5200
	Q(PREDICTED)	1320	3670	6050	10000	14100	18100	-
	Q(WEIGHTED)	1690	3660	5540	8550	11300	14000	-
6131000	Q(STATION)	2780	8270	14000	23700	32800	43400	24600
	Q(PREDICTED)	1990	5370	8710	14200	19700	25100	-
	Q(WEIGHTED)	2700	7710	12800	21200	29600	39000	-
6172300	Q(STATION)	85	421	906	1940	3100	4620	4460
	Q(PREDICTED)	140	466	838	1520	2220	3010	-
	Q(WEIGHTED)	95	435	882	1780	2780	4030	-
6172350	Q(STATION)	39	124	217	379	532	712	400
	Q(PREDICTED)	111	366	649	1160	1670	2230	-
	Q(WEIGHTED)	56	215	405	746	1040	1390	-
6174000	Q(STATION)	2640	6630	10300	16000	20900	26400	16000
	Q(PREDICTED)	1080	3080	5050	8280	11400	14400	-
	Q(WEIGHTED)	2400	5680	8640	13300	17800	22500	-
6175550	Q(STATION)	180	478	763	1220	1620	2070	1220
	Q(PREDICTED)	163	547	982	1770	2590	3500	-
	Q(WEIGHTED)	176	504	859	1480	2060	2710	-
6175700	Q(STATION)	62	243	467	896	1330	1870	2230
	Q(PREDICTED)	98	262	604	889	1660	2300	-
	Q(WEIGHTED)	68	248	513	893	1440	2020	-
6175900	Q(STATION)	108	423	811	1550	2310	3240	3900
	Q(PREDICTED)	138	468	847	1550	2260	3080	-
	Q(WEIGHTED)	113	435	823	1550	2290	3190	-
6176500	Q(STATION)	455	2060	4240	8690	13400	19600	9780
	Q(PREDICTED)	1010	2970	5000	8430	11900	15400	-
	Q(WEIGHTED)	540	2300	4480	8600	12900	18200	-
6177050	Q(STATION)	94	253	411	672	910	1180	650
	Q(PREDICTED)	69	231	421	778	1160	1600	-
	Q(WEIGHTED)	90	247	414	710	994	1320	-

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
	DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES							
	EAST-CENTRAL PLAINS REGION--Continued							
6177100	Q(STATION)	215	632	1070	1820	2520	3340	1000
	Q(PREDICTED)	177	558	986	1770	2580	3480	-
	Q(WEIGHTED)	206	604	1030	1800	2550	3400	-
6177150	Q(STATION)	486	1340	2190	3590	4870	6340	1900
	Q(PREDICTED)	457	1350	2320	3990	5700	7500	-
	Q(WEIGHTED)	480	1340	2240	3770	5220	6820	-
6177200	Q(STATION)	130	339	539	860	1150	1470	430
	Q(PREDICTED)	228	706	1240	2190	3190	4300	-
	Q(WEIGHTED)	152	472	834	1460	2030	2690	-
6177250	Q(STATION)	7	75	234	742	1510	2790	1610
	Q(PREDICTED)	40	142	263	495	741	1040	-
	Q(WEIGHTED)	14	98	246	634	1190	2060	-
6177300	Q(STATION)	8	37	80	172	276	416	234
	Q(PREDICTED)	12	48	93	183	282	406	-
	Q(WEIGHTED)	9	41	85	177	279	412	-
6177350	Q(STATION)	31	62	88	124	152	183	85
	Q(PREDICTED)	41	143	264	493	740	1030	-
	Q(WEIGHTED)	33	90	159	286	398	535	-
6177400	Q(STATION)	92	363	706	1380	4060	2970	1000
	Q(PREDICTED)	168	543	968	1740	2550	3460	-
	Q(WEIGHTED)	107	423	809	1530	3460	3170	-
6177500	Q(STATION)	1130	2950	4650	7340	9680	12300	6730
	Q(PREDICTED)	1090	3120	5210	8790	12400	16100	-
	Q(WEIGHTED)	1130	2980	4770	7700	10300	13200	-
6177700	Q(STATION)	73	265	489	905	1320	1820	750
	Q(PREDICTED)	64	230	429	805	1200	1670	-
	Q(WEIGHTED)	71	252	464	860	1270	1760	-
6177800	Q(STATION)	46	271	629	1460	2430	3770	1500
	Q(PREDICTED)	46	169	319	607	912	1280	-
	Q(WEIGHTED)	46	235	503	1090	1800	2730	-
6181000	Q(STATION)	3800	11700	20100	34400	47900	63600	40000
	Q(PREDICTED)	3840	10200	16400	26500	36400	45700	-
	Q(WEIGHTED)	3810	11400	19100	32000	44600	58500	-
6181200	Q(STATION)	54	117	170	245	306	371	313
	Q(PREDICTED)	38	135	249	457	532	910	-
	Q(WEIGHTED)	50	124	204	345	407	612	-
6185100	Q(STATION)	41	187	385	791	1230	1780	676
	Q(PREDICTED)	94	313	556	979	1400	1850	-
	Q(WEIGHTED)	53	235	460	879	1310	1810	-
6185200	Q(STATION)	12	131	409	1270	2520	4540	2570
	Q(PREDICTED)	44	157	288	530	774	1050	-
	Q(WEIGHTED)	19	141	356	922	1740	2980	-
6185300	Q(STATION)	314	645	909	1280	1580	1880	1670
	Q(PREDICTED)	146	479	843	1480	2120	2790	-
	Q(WEIGHTED)	275	582	880	1370	1820	2290	-
6185400	Q(STATION)	55	214	409	781	1160	1620	1325
	Q(PREDICTED)	74	256	463	838	1220	1640	-
	Q(WEIGHTED)	59	229	432	807	1190	1630	-
6217700	Q(STATION)	156	653	1410	3260	5650	9310	5120
	Q(PREDICTED)	81	282	535	1040	1610	2330	-
	Q(WEIGHTED)	140	524	1060	2290	3960	6410	-
6294900	Q(STATION)	63	151	237	382	519	683	463
	Q(PREDICTED)	24	89	172	341	530	771	-
	Q(WEIGHTED)	54	128	209	363	524	722	-
6295020	Q(STATION)	116	490	1030	2250	3710	5790	938
	Q(PREDICTED)	60	213	398	755	1140	1600	-
	Q(WEIGHTED)	104	393	774	1590	2640	4050	-

Table 1.--*Annual flood magnitude-frequency data for streamflow-gaging stations*--Continued

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES						
			EAST-CENTRAL PLAINS REGION--Continued					
6295050	Q(STATION)	1650	3200	4490	6410	8040	9850	9350
	Q(PREDICTED)	780	2230	3740	6320	8950	11600	-
	Q(WEIGHTED)	1480	2870	4200	6370	8410	10600	-
6309020	Q(STATION)	9	24	40	66	90	119	39
	Q(PREDICTED)	16	58	112	222	342	494	-
	Q(WEIGHTED)	11	37	70	137	199	280	-
6309040	Q(STATION)	132	459	858	1640	2460	3520	1500
	Q(PREDICTED)	218	703	1250	1430	3330	4540	-
	Q(WEIGHTED)	152	551	1030	1540	2850	3980	-
6309060	Q(STATION)	47	111	173	272	363	467	320
	Q(PREDICTED)	16	622	122	245	380	553	-
	Q(WEIGHTED)	41	289	152	260	370	503	-
6326900	Q(STATION)	77	165	239	347	436	531	338
	Q(PREDICTED)	20	117	140	268	403	565	-
	Q(WEIGHTED)	64	147	196	310	421	546	-
6326950	Q(STATION)	21	78	145	271	398	553	267
	Q(PREDICTED)	25	91	171	327	491	687	-
	Q(WEIGHTED)	22	83	156	296	438	611	-
			SOUTHEAST PLAINS REGION					
6294400	Q(STATION)	7	17	27	45	62	84	40
	Q(PREDICTED)	15	41	72	127	184	256	-
	Q(WEIGHTED)	8	21	37	70	104	147	-
6294800	Q(STATION)	123	455	904	1880	3030	4640	800
	Q(PREDICTED)	116	305	482	800	1100	1470	-
	Q(WEIGHTED)	122	428	805	1540	2340	3430	-
6294850	Q(STATION)	25	84	158	309	478	706	398
	Q(PREDICTED)	22	58	101	178	256	355	-
	Q(WEIGHTED)	25	79	145	267	399	573	-
6295100	Q(STATION)	96	214	328	520	702	921	540
	Q(PREDICTED)	110	285	448	740	1020	1350	-
	Q(WEIGHTED)	98	227	356	590	815	1080	-
6295200	Q(STATION)	9	23	39	66	94	129	45
	Q(PREDICTED)	4	12	21	40	59	84	-
	Q(WEIGHTED)	8	21	35	58	82	112	-
6296000	Q(STATION)	321	695	1070	1730	2390	3230	3280
	Q(PREDICTED)	369	889	1400	2320	3220	4350	-
	Q(WEIGHTED)	325	724	1130	1890	2640	3600	-
6296100	Q(STATION)	102	236	362	566	753	970	410
	Q(PREDICTED)	64	170	272	454	630	841	-
	Q(WEIGHTED)	98	224	341	530	709	921	-
6306300	Q(STATION)	4020	5870	7150	8810	10100	11400	17500
	Q(PREDICTED)	975	2340	3650	6030	8340	11200	-
	Q(WEIGHTED)	3840	5510	6670	8270	9710	11400	-
6306900	Q(STATION)	120	383	709	1380	2120	3150	1400
	Q(PREDICTED)	324	839	1280	2060	2790	3660	-
	Q(WEIGHTED)	136	445	812	1550	2310	3310	-
6306950	Q(STATION)	42	115	198	353	516	728	222
	Q(PREDICTED)	52	138	224	377	525	703	-
	Q(WEIGHTED)	43	118	203	359	519	720	-
6307640	Q(STATION)	131	278	411	623	815	1040	2080
	Q(PREDICTED)	26	70	117	202	286	390	-
	Q(WEIGHTED)	120	240	342	489	627	793	-
6307660	Q(STATION)	5	22	47	105	176	282	58
	Q(PREDICTED)	24	66	109	187	263	356	-
	Q(WEIGHTED)	7	29	61	130	206	309	-

Table 1.--*Annual flood magnitude-frequency data for streamflow-gaging stations*--Continued

STATION		Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES						
		SOUTHEAST PLAINS REGION--Continued						
6307760	Q(STATION)	3	9	15	29	43	61	39
	Q(PREDICTED)	10	26	47	86	126	179	-
	Q(WEIGHTED)	4	12	23	47	73	106	-
6307780	Q(STATION)	83	302	593	1210	1930	2920	570
	Q(PREDICTED)	49	127	214	372	531	735	-
	Q(WEIGHTED)	80	272	508	955	1450	2120	-
6308200	Q(STATION)	13	44	83	160	244	355	390
	Q(PREDICTED)	18	53	86	145	200	266	-
	Q(WEIGHTED)	14	45	83	157	233	330	-
6308300	Q(STATION)	163	519	944	1770	2650	3800	990
	Q(PREDICTED)	166	551	839	1360	1830	2390	-
	Q(WEIGHTED)	163	524	924	1660	2400	3350	-
6309080	Q(STATION)	614	1320	1940	2880	3680	4580	2430
	Q(PREDICTED)	251	665	998	1600	2140	2770	-
	Q(WEIGHTED)	579	1210	1740	2510	3170	3940	-
6309090	Q(STATION)	20	81	166	347	552	833	1400
	Q(PREDICTED)	41	110	181	309	436	590	-
	Q(WEIGHTED)	22	86	170	335	511	741	-
6317050	Q(STATION)	99	361	708	1460	2320	3520	3120
	Q(PREDICTED)	134	361	553	895	1210	1580	-
	Q(WEIGHTED)	102	361	676	1300	1970	2860	-
6324700	Q(STATION)	27	97	188	378	593	887	715
	Q(PREDICTED)	81	214	333	545	743	979	-
	Q(WEIGHTED)	31	111	211	416	632	912	-
6325500	Q(STATION)	1130	1830	2350	3060	3620	4220	3160
	Q(PREDICTED)	1220	2950	4220	6530	8650	11100	-
	Q(WEIGHTED)	1140	1960	2640	3820	4870	6070	-
6326400	Q(STATION)	252	492	687	971	1210	1460	1370
	Q(PREDICTED)	67	176	287	488	684	927	-
	Q(WEIGHTED)	232	435	593	817	1020	1260	-
6326600	Q(STATION)	1220	2870	4390	6790	8920	11300	4700
	Q(PREDICTED)	1280	3160	4480	6890	9040	11500	-
	Q(WEIGHTED)	1230	2920	4410	6820	8960	11400	-
6326650	Q(STATION)	31	52	67	88	104	120	61
	Q(PREDICTED)	10	29	48	81	111	148	-
	Q(WEIGHTED)	29	48	63	86	106	131	-
6326700	Q(STATION)	110	155	183	218	242	267	225
	Q(PREDICTED)	38	105	164	269	366	479	-
	Q(WEIGHTED)	102	146	179	234	286	348	-
6326800	Q(STATION)	61	102	137	187	226	267	350
	Q(PREDICTED)	30	82	128	211	288	379	-
	Q(WEIGHTED)	58	99	135	194	246	306	-
6328800	Q(STATION)	12	50	98	191	287	407	150
	Q(PREDICTED)	23	66	105	174	239	316	-
	Q(WEIGHTED)	13	53	100	186	271	374	-
6328900	Q(STATION)	8	23	40	67	93	122	62
	Q(PREDICTED)	81	218	334	542	733	955	-
	Q(WEIGHTED)	15	56	106	212	312	426	-
6329570	Q(STATION)	46	759	289	523	751	1020	700
	Q(PREDICTED)	280	728	1070	1700	2260	2910	-
	Q(WEIGHTED)	70	754	463	881	1270	1710	-
6334000	Q(STATION)	1820	3340	4490	6040	7260	8510	6000
	Q(PREDICTED)	1180	2880	4200	6580	8770	11300	-
	Q(WEIGHTED)	1800	3310	4470	6100	7460	8920	-
6334100	Q(STATION)	261	567	850	1300	1720	2200	1170
	Q(PREDICTED)	173	461	695	1110	1500	1940	-
	Q(WEIGHTED)	255	554	825	1260	1660	2130	-

STATION		DISCHARGES, IN CUBIC FEET PER SECOND, FOR SELECTED EXCEEDANCE PROBABILITIES Q(50%)	Q(20%)	Q(10%)	Q(4%)	Q(2%)	Q(1%)	MAXIMUM OF RECORD
				SOUTHEAST PLAINS REGION--Continued				
6334200	Q(STATION)	558	1270	1940	3050	4080	5290	1800
	Q(PREDICTED)	813	2060	2970	4610	6080	7740	-
	Q(WEIGHTED)	584	1410	2170	3520	4760	6180	-
6334500	Q(STATION)	2710	4740	6310	8510	10300	12200	9420
	Q(PREDICTED)	1720	4140	5860	9040	11900	15200	-
	Q(WEIGHTED)	2640	4670	6240	8630	10700	13000	-
6334630	Q(STATION)	2000	4900	7720	12400	16700	21700	23000
	Q(PREDICTED)	2100	5120	7280	11200	14800	18900	-
	Q(WEIGHTED)	2010	4940	7620	12000	16000	20600	-
6334640	Q(STATION)	122	459	865	1630	2400	3340	750
	Q(PREDICTED)	233	615	920	1470	1960	2540	-
	Q(WEIGHTED)	134	487	878	1580	2240	3040	-
6334720	Q(STATION)	12	38	69	128	188	264	106
	Q(PREDICTED)	67	182	282	461	627	818	-
	Q(WEIGHTED)	17	61	114	225	332	459	-
6335000	Q(STATION)	3410	5950	7810	10300	12200	14200	12700
	Q(PREDICTED)	2060	5080	7100	10800	14100	17800	-
	Q(WEIGHTED)	3350	5880	7740	10400	12500	14900	-
6335700	Q(STATION)	12	27	41	62	80	100	58
	Q(PREDICTED)	11	32	52	80	122	161	-
	Q(WEIGHTED)	12	28	43	67	93	120	-
6336100	Q(STATION)	25	47	64	99	124	154	147
	Q(PREDICTED)	14	40	64	108	148	196	-
	Q(WEIGHTED)	24	46	64	102	133	170	-
6336200	Q(STATION)	41	101	156	239	310	387	210
	Q(PREDICTED)	18	50	79	132	181	239	-
	Q(WEIGHTED)	39	92	139	206	266	333	-
6336300	Q(STATION)	3	17	39	86	141	215	200
	Q(PREDICTED)	15	42	68	114	156	207	-
	Q(WEIGHTED)	4	21	45	94	146	212	-
6336400	Q(STATION)	175	401	596	885	1120	1380	629
	Q(PREDICTED)	65	176	270	438	592	771	-
	Q(WEIGHTED)	165	368	532	765	959	1180	-
6336450	Q(STATION)	67	156	235	353	453	562	438
	Q(PREDICTED)	66	178	273	443	598	780	-
	Q(WEIGHTED)	67	160	243	379	501	639	-
6336500	Q(STATION)	899	3470	6830	13800	21400	31700	30000
	Q(PREDICTED)	957	3780	5330	8170	10700	13500	-
	Q(WEIGHTED)	902	3500	6660	12900	19300	27900	-
6336980	Q(STATION)	250	670	1070	1710	2270	2900	1050
	Q(PREDICTED)	73	198	308	502	682	891	-
	Q(WEIGHTED)	230	580	882	1310	1680	2100	-
6337100	Q(STATION)	253	674	1080	1710	2270	2900	1100
	Q(PREDICTED)	266	697	1030	1640	2180	2810	-
	Q(WEIGHTED)	254	678	1070	1690	2240	2860	-
6356000	Q(STATION)	619	1440	2210	3460	4600	5910	2780
	Q(PREDICTED)	546	1380	1990	3090	4070	5200	-
	Q(WEIGHTED)	614	1430	2170	3380	4460	5710	-
6358600	Q(STATION)	54	124	192	302	405	526	450
	Q(PREDICTED)	49	133	206	355	455	594	-
	Q(WEIGHTED)	53	125	194	315	419	546	-
6358620	Q(STATION)	21	36	46	61	73	85	64
	Q(PREDICTED)	4	13	21	37	51	69	-
	Q(WEIGHTED)	19	32	40	54	65	79	-

Table 2.--*Basin characteristics at gaging stations*

Station number	Station name	Years of record	Drainage area (*A*) (square miles)	Mean annual precipitation (*P*) (inches)
	West Region			
12300500	Fortine Cr nr Trego, Mont	23	112	29
12300800	Deep Cr nr Fortine, Mont	20	18.9	49
12301300	Tobacco R nr Eureka, Mont	21	440	33
12301700	Kootenai R trib nr Rexford, Mont	12	.86	30
12301800	Gold Cr nr Rexford, Mont	11	6.12	31
12302000	Fisher R nr Jennings, Mont	29	780	32
12302400	Shaughnessy Cr nr Libby, Mont	20	1.16	60
12302500	Granite Cr nr Libby, Mont	23	23.6	67
12303100	Flower Cr nr Libby, Mont	18	11.1	79
12303500	Lake Cr at Troy, Mont	14	210	67
12304250	Whitetail Cr nr Yaak, Mont	15	2.48	37
12304300	Cyclone Cr nr Yaak, Mont	19	5.73	65
12304400	Fourth of July Cr nr Yaak, Mont	15	7.84	68
12304500	Yaak R nr Troy, Mont	25	766	43
12323300	Smith Gulch nr Silverbow, Mont	20	4.85	12
12323500	German Gulch Cr nr Ramsay, Mont	13	40.6	18
12324100	Racetrack Cr bl Granite Cr nr Anaconda, Mont	17	39.5	35
12324700	Clark Fk trib nr Drummond, Mont	21	4.61	15
12324800	Morris Cr nr Drummond, Mont	15	12.6	18
12330000	Boulder Cr at Maxville, Mont	39	71.3	31
12332000	M Fk Rock Cr nr Phillipsburg, Mont	40	123	36
12335500	Nevada Cr ab Reservoir nr Finn, Mont	39	116	23
12338500	Blackfoot R nr Ovando, Mont	25	1,270	29
12339900	W Twin Cr nr Bonner, Mont	20	7.33	24
12340000	Blackfoot R nr Bonner, Mont	44	2,290	29
12340200	Marshall Cr nr Missoula, Mont	15	5.63	23
12341000	Rattlesnake Cr at Missoula, Mont	10	79.7	34
12343400	E Fk Bitterroot R nr Connor, Mont	36	381	32
12344300	Burke Gulch nr Darby, Mont	21	6.50	20
12345800	Camas Cr nr Hamilton, Mont	16	5.05	75
12346500	Skalkaho Cr nr Hamilton, Mont	28	87.8	36
12347500	Blodgett Cr nr Corvallis, Mont	30	26.4	73
12348500	Willow Cr nr Corvallis, Mont	19	22.4	33
12350000	Bear Cr nr Victor, Mont	19	26.8	76
12350200	Gash Cr nr Victor, Mont	16	3.37	70
12350500	Kootenai Cr nr Stevensville, Mont	22	28.9	76
12351000	Burnt Fk Bitterroot R nr Stevensville, Mont	40	74.0	32
12351400	Eightmile Cr nr Florence, Mont	16	20.6	20
12352000	Lolo Cr ab Sleeman Cr nr Lolo, Mont	12	250	52
12352200	Hayes Cr nr Missoula, Mont	15	4.16	33
12353400	Negro Gulch nr Alberton, Mont	15	8.02	33
12353800	Thompson Cr nr Superior, Mont	18	12.2	43
12353850	E Fk Timber Cr nr Haugan, Mont	15	2.72	58
12354000	St Regis R nr St Regis, Mont	26	303	52
12354100	N Fk Little Joe Cr nr St Regis, Mont	15	14.7	56
12363900	Rock Cr nr Olney, Mont	15	3.61	35
12364000	Logan Cr at Tally Lake nr Whitefish, Mont	10	183	28
12365000	Stillwater R nr Whitefish, Mont	27	524	31
12366000	Whitefish Cr nr Kalispell, Mont	29	170	37
12370500	Dayton Cr nr Proctor, Mont	20	20.9	20
12370900	Teepee Cr nr Polson, Mont	15	2.55	52
12371100	Hellroaring Cr nr Polson, Mont	26	6.22	48
12374300	Mill Cr nr Niarada, Mont	15	28.2	27
12375700	Garden Cr nr Hot Springs, Mont	15	3.29	19
12378000	Mission Cr nr St Ignatius, Mont	11	74.8	48
12389500	Thompson R nr Thompson Falls, Mont	24	642	41
12390700	Prospect Cr at Thompson Falls, Mont	23	182	54

Table 2.--*Basin characteristics at gaging stations*--Continued

Station number	Station name	Years of record	Drainage area (*A*) (square miles)	Mean annual precipitation (*P*) (inches)
	Northwest Region			
5010000	Belly R at international boundary	17	74.8	79
5011000	Belly R nr Mountain View, Alberta	68	121	65
5012500	Boundary Cr at international boundary	17	21.0	75
5013000	Waterton R nr Waterton Park, Alberta	55	238	68
5014000	Grinnell Cr nr Many Glacier, Mont	29	3.47	95
5014500	Swiftcurrent Cr at Many Glacier, Mont	66	31.4	95
5015000	Canyon Cr nr Many Glacier, Mont	13	7.09	105
6073000	Dearborn R nr Clemons, Mont	28	123	37
6078500	N Fk Sun R nr Augusta, Mont	25	258	42
6079600	Beaver Cr at Gibson Dam nr Augusta, Mont	15	20.3	29
6080000	Sun R nr Augusta, Mont	26	609	42
6081500	Willow Cr nr Augusta, Mont	20	96.1	21
6084500	Elk Cr at Augusta, Mont	20	157	21
6092000	Two Medicine R nr Browning, Mont	43	317	36
6092500	Badger Cr nr Browning, Mont	24	133	39
6098000	Dupuyer Cr nr Valier, Mont	24	137	25
6102500	Teton R nr Farmington, Mont	19	105	35
6132200	S Fk Milk R nr Babb, Mont	18	68.6	36
12335000	Blackfoot R nr Helmville, Mont	16	481	15
12355000	N Fk Flathead R at Flathead, B C	50	450	55
12355500	N Fk Flathead R nr Columbia Falls, Mont	57	1,550	26
12356000	Skyland Cr nr Essex, Mont	25	8.37	47
12356500	Bear Cr nr Essex, Mont	12	20.7	51
12357000	M Fk Flathead R at Essex, Mont	24	510	52
12357300	Moccasin Cr nr West Glacier, Mont	17	2.38	57
12357400	M Fk Flathead R trib at West Glacier, Mont	15	.14	39
12358500	M Fk Flathead R nr West Glacier, Mont	39	1,130	59
12359000	S Fk Flathead R at Spotted Bear Ranger Station, Mont	18	958	52
12359500	Spotted Bear R nr Hungry Horse, Mont	10	184	56
12359800	S Fk Flathead R ab Twin Cr nr Hungry Horse, Mont	15	1,160	52
12360000	Twin Cr nr Hungry Horse, Mont	13	47.0	53
12361000	Sullivan Cr nr Hungry Horse, Mont	26	71.3	35
12361500	Graves Cr nr Hungry Horse, Mont	13	27.0	67
12362500	S Fk Flathead R nr Columbia Falls, Mont	42	1,660	37

Station number	Station name	Years of record	Drainage area (*A*) (square miles)	Basin above 6000 feet elevation (*HE*) (percent)
	Southwest Region			
6011000	Red Rock R nr Lakeview, Mont	28	323	100.0
6013200	Traux Cr nr Lima, Mont	15	4.06	100.0
6013400	Muddy Cr nr Dell, Mont	15	62.7	99.0
6013500	Big Sheep Cr bl Muddy Cr nr Dell, Mont	27	280	99.0
6015500	Grasshopper Cr nr Dillon, Mont	39	348	94.0
6017500	Blacktail Deer Cr nr Dillon, Mont	20	312	96.0
6019500	Ruby R ab Reservoir nr Alder, Mont	40	538	91.0
6019800	Idaho Cr nr Alder, Mont	19	11.0	83.0
6025300	Moose Cr nr Divide, Mont	15	41.4	97.0
6025500	Big Hole R nr Melrose, Mont	55	2,480	91.0
6027700	Fish Cr nr Silverstar, Mont	20	39.5	80.0
6029000	Whitetail Cr nr Whitehall, Mont	18	30.8	97.2
6030300	Jefferson R trib No. 2 nr Whitehall, Mont	22	4.50	31.0
6030500	Boulder R ab Rock Cr nr Basin, Mont	11	19.4	100.0
6033000	Boulder R nr Boulder, Mont	44	381	80.0
6034700	Sand Cr at Sappington, Mont	15	9.41	0.0
6034800	Jefferson R trib 3 nr Sappington, Mont	15	1.14	0.0
6035000	Willow Cr nr Harrison, Mont	41	83.8	70.7
6036600	Jefferson R trib 4 nr Three Forks, Mont	15	0.53	0.0
6037500	Madison R nr West Yellowstone, Mont	59	420	99.0
6055500	Crow Cr nr Radersburg, Mont	18	78.0	86.0
6056200	Castle Cr trib nr Ringling, Mont	15	2.59	80.0
6056300	Cabin Cr nr Townsend, Mont	19	12.6	44.0
6056600	Deep Cr bl N Fk Deep Cr nr Townsend, Mont	16	87.7	61.0
6058700	Mitchell Gulch nr East Helena, Mont	20	8.09	12.0
6061500	Prickly Pear Cr nr Clancy, Mont	41	192	34.0
6061700	Jackson Cr nr East Helena, Mont	15	3.44	59.3
6061800	Crystal Cr nr East Helena, Mont	15	3.77	38.9
6061900	McClellan Cr at City Diversion Dam nr East Helena, Mont	16	33.2	47.0
6062500	Tenmile Cr nr Rimini, Mont	64	32.7	86.2
6062700	Little Porcupine Cr trib nr Helena, Mont	15	.48	76.5
6063000	Tenmile Cr nr Helena, Mont	47	102	39.5
6068500	Little Prickly Pear Cr nr Marysville, Mont	20	44.4	55.0
6071200	Lyons Cr nr Wolf Cr, Mont	16	29.4	13.0
6071400	Dog Cr nr Craig, Mont	16	15.9	0.0
6071600	Wegner Cr at Craig, Mont	19	35.0	3.0

Table 2.--*Basin characteristics at gaging stations*--Continued

Station number	Station name	Years of record	Drainage area (*A*) (square miles)	Mean basin elevation (*E*) (feet) above sea level)	Basin above 6000 feet elevation (*HE*) (percent)
	Upper Yellowstone-Central Mountain Region				
6043000	Taylor Cr nr Grayling, Mont	11	98.0	8,320	99.0
6043200	Squaw Cr nr Gallatin Gateway, Mont	17	40.4	7,440	98.0
6043300	Logger Cr nr Gallatin Gateway, Mont	20	2.48	7,120	87.0
6043500	Gallatin R nr Gallatin Gateway, Mont	69	825	7,960	95.0
6046500	Rocky Cr nr Bozeman, Mont	22	49.0	6,110	55.0
6046700	Pitcher Cr nr Bozeman, Mont	16	2.33	5,680	15.0
6047000	Bear Canyon nr Bozeman, Mont	18	17.0	6,690	92.0
6048000	E Gallatin R at Bozeman, Mont	22	148	6,210	51.0
6048500	Bridger Cr nr Bozeman, Mont	25	62.5	6,540	62.0
6050000	Hyalite Cr at Hyalite Ranger Station nr Bozeman, Mont	19	48.2	7,710	97.0
6052500	Gallatin R at Logan, Mont	59	1,800	6,820	64.0
6074500	Smith R nr White Sulphur Springs, Mont	12	30.7	6,770	81.0
6075600	Fivemile Cr nr White Sulphur Springs, Mont	15	6.00	5,980	45.0
6076000	Newland Cr nr White Sulphur Springs, Mont	22	6.74	6,380	81.0
6076700	Sheep Cr nr Neihart, Mont	19	5.22	7,210	99.0
6076800	Nuggett Cr nr Neihart, Mont	15	1.48	7,190	99.0
6077000	Sheep Cr nr White Sulphur Springs, Mont	32	54.4	6,910	94.0
6077500	Smith R nr Eden, Mont	20	1,590	5,840	35.6
6077700	Smith R trib nr Eden, Mont	15	1.44	3,840	0.0
6077800	Goodman Coulee nr Eden, Mont	20	21.8	4,020	0.0
6090500	Belt Cr nr Monarch, Mont	27	368	6,190	56.0
6109800	S Fk Judith R nr Utica, Mont	20	58.7	6,640	94.0
6115500	N Fk Musselshell R nr Delpine, Mont	38	31.4	6,120	77.0
6117000	Checkerboard Cr at Delpine, Mont	10	23.9	6,340	77.0
6118500	S Fk Musselshell R ab Martinsdale, Mont	37	287	6,110	60.0
6120500	Musselshell R at Harlowton, Mont	70	1,130	5,650	38.8
6122000	American Fk bl Lebo Cr nr Harlowton, Mont	22	166	5,480	24.8
6187500	Tower Cr at Tower Fls Yellowstone Natl Pk, Wyo	21	50.4	8,340	99.0
6188000	Lamar R nr Tower Falls Rngr Sta Yellowstone Park, Wyo	47	660	7,400	91.0
6191000	Gardner R nr Mammoth Yellowstone Natl Pk, Mont	50	202	7,940	98.0
6191500	Yellowstone R at Corwin Springs, Mont	72	2,620	8,440	96.0
6193000	Shields R nr Wilsall, Mont	22	87.8	7,040	97.0
6193500	Shields R Clyde Park, Mont	41	543	6,090	44.1
6194000	Brackett Cr nr Clyde Park, Mont	27	57.9	6,140	60.0
6197000	Big Timber Cr nr Big Timber, Mont	13	74.9	6,680	59.0
6197500	Boulder R nr Contact, Mont	32	226	8,510	91.0
6200000	Boulder R at Big Timber, Mont	31	523	7,570	75.0
6200500	Sweet Grass Cr ab Melville, Mont	46	63.8	7,630	75.0
6201000	Sweet Grass Cr bl Melville, Mont	30	143	6,110	32.8
6201550	Yellowstone R trib nr Greycliff, Mont	15	2.72	4,290	0.0
6201600	Bridger Cr nr Greycliff, Mont	16	61.5	5,320	12.0
6201650	Work Cr nr Reed Point, Mont	16	32.5	4,630	0.0
6201700	Hump Cr nr Reed Point, Mont	19	7.61	4,420	0.0
6204050	W Rosebud Cr nr Roscoe, Mont	13	52.1	9,560	100.0
6204500	Rosebud Cr nr Absarokee, Mont	35	394	7,890	66.1

Table 2.--*Basin characteristics at gaging stations*--Continued

Station number	Station name	Years of record	Drainage area (*A*) (square miles)	Mean basin elevation (*E*) (feet above sea level)	Basin above 6000 feet elevation (*HE*) (percent)
	Upper Yellowstone-Central Mountain Region--Continued				
6205000	Stillwater R nr Absarokee, Mont	48	975	7,220	53.0
6205100	Allen Cr nr Park City, Mont	18	7.17	3,960	0.0
6206500	Sunlight Cr nr Painter, Wyo	30	135	8,500	100.0
6207500	Clarks Fk Yellowstone R nr Belfry, Mont	57	1,150	7,430	80.0
6207800	Bluewater Cr nr Bridger, Mont	11	28.1	4,860	0.0
6208500	Clarks Fk Yellowstone R at Edgar, Mont	56	2,030	6,130	45.0
6209500	Rock Cr nr Red Lodge, Mont	46	124	9,540	99.0
6210000	W Fk Rock Cr bl Basin Cr nr Red Lodge, Mont	24	63.1	9,050	100.0
6211000	Red Lodge Cr ab Cooney Reservoir nr Boyd, Mont	42	143	5,710	23.6
6211500	Willow Cr nr Boyd, Mont	42	53.3	4,730	8.1
6215000	Pryor Cr ab Pryor, Mont	12	39.6	6,000	48.4
6216000	Pryor Cr at Pryor, Mont	14	117	5,280	41.0
6216200	W Wets Cr nr Billings, Mont	24	8.80	3,980	0.0
6216300	W Buckeye Cr nr Billings, Mont	20	2.64	3,780	0.0
6216500	Pryor Cr nr Billings, Mont	49	440	4,550	12.0
6287500	Soap Cr nr St Xavier, Mont	22	98.3	4,240	5.0
6288200	Beauvais Cr nr St Xavier, Mont	11	100	4,210	0.0
6289000	Little Bighorn R at State line nr Wyola, Mont	40	193	7,830	93.0
6290000	Pass Cr nr Wyola, Mont	22	111	5,570	15.0
6290500	Little Bighorn R bl Pass Cr nr Wyola, Mont	38	428	6,140	47.0
6291500	Lodgepass Cr ab Willow Cr Diversion, Mont	37	80.7	6,360	52.0
6294000	Little Bighorn R nr Hardin, Mont	26	1,290	4,770	19.8
6298000	Tongue R nr Dayton, Wyo	49	204	8,330	92.0
6298500	Little Tongue R nr Dayton, Wyo	23	25.1	7,560	80.0
6299500	Wolf Cr at Wolf, Wyo	35	37.8	7,700	90.0
6300500	E Fk Big Goose Cr nr Big Horn, Wyo	25	20.3	9,560	100.0

Table 2.--*Basin characteristics at gaging stations*--Continued

Station number	Station name	Years of record	Drainage area (*A*) (square miles)	Mean basin elevation (*E*) (feet above sea level)
	Northwest-Foothills Region			
6087900	Muddy Cr trib nr Power, Mont	16	3.15	3,840
6088500	Muddy Cr at Vaughn, Mont	43	314	3,840
6089300	Sun R trib nr Great Falls, Mont	19	21.1	3,510
6099700	M Fk Dry Fk Marias R nr Dupuyer, Mont	15	20.2	4,590
6100200	Heines Coulee trib nr Valier, Mont	16	0.60	3,910
6100300	Lone Man Coulee nr Valier, Mont	19	14.1	3,890
6101600	Marias R trib No. 3 nr Chester, Mont	16	0.26	2,990
6101700	Fey Coulee trib nr Chester, Mont	16	2.47	3,260
6101800	Sixmile Coulee nr Chester, Mont	15	24.6	3,110
6101900	Dead Indian Coulee nr Fort Benton, Mont	15	2.85	3,340
6102100	Dry Fk Coulee trib nr Loma, Mont	15	0.84	2,770
6102200	Marias R trib at Loma, Mont	17	1.62	2,830
6102300	Marias R trib No. 2 at Loma, Mont	17	0.25	2,750
6105800	Bruce Coulee trib nr Choteau, Mont	16	1.70	4,170
6108200	Kinley Coulee nr Dutton, Mont	16	9.67	3,700
6108300	Kinley Coulee trib nr Dutton, Mont	15	2.65	3,760
6132400	Dry Fk Milk R nr Babb, Mont	17	17.4	5,130
6133000	Milk R at Western Crossing of international boundary	47	397	4,870
6133500	N Fk Milk R ab St Mary Canal nr Browning, Mont	39	61.8	4,850
6134500	Milk R at Milk River, Alberta	67	1,040	4,010
6134800	Van Cleeve Coulee trib nr Sunburst, Mont	16	10.8	3,600

Table 2.--*Basin characteristics at gaging stations*--Continued

Station number	Station name	Years of record	Drainage area (*A*) (square miles)	Mean basin elevation (*E*) (feet above sea level)	Mean minimum January temperature (*TI*) (degrees F)
	Northeast Plains Region				
6109900	Judith R trib nr Utica, Mont	15	7.15	5,420	7
6110000	Judith R nr Utica, Mont	55	328	6,540	7
6111700	Mill Cr nr Lewistown, Mont	19	3.14	4,630	8
6112100	Cottonwood Cr nr Moore, Mont	17	47.9	5,840	9
6128400	S Fk Bear Cr nr Roy, Mont	15	39.6	3,570	10
6128500	S Fk Bear Cr trib nr Roy, Mont	17	5.40	3,430	10
6129100	N Fk McDonald Cr trib nr Heath, Mont	16	2.24	4,750	8
6129200	Alkali Cr nr Heath, Mont	15	3.76	4,570	8
6129400	S Fk McDonald Cr trib nr Grassrange, Mont	15	0.51	3,850	8
6129500	McDonald Cr at Winnett, Mont	36	421	4,140	8
6135500	Sage Cr at Q Ranch nr Wild Horse, Alberta	38	175	3,200	-1
6137900	England Coulee at Hingham, Mont	15	0.93	3,090	2
6138700	S Fk Spring Coulee nr Havre, Mont	19	6.47	3,100	4
6138800	Spring Coulee nr Havre, Mont	15	17.8	3,090	4
6139500	Big Sand Cr nr Assinniboine, Mont	21	1,810	3,200	4
6140400	Bullhook Cr nr Havre, Mont	15	39.6	3,220	5
6141900	Milk R trib nr Lohman, Mont	15	0.11	2,500	4
6144350	Middle Cr nr Alberta Boundary	15	116	3,970	-3
6144500	Lodge Cr at international boundary	41	753	3,480	-1
6145000	McRae Cr at international boundary	20	59.0	2,900	-1
6148000	Battle Cr ab Cypress Lake nr West Plains, Sask	28	270	4,070	-1
6150000	Woodpile Coulee nr international boundary	44	60.2	2,950	-1
6150500	E Fk Battle Cr nr international boundary	44	89.5	3,000	-1
6151000	Lyons Cr at international boundary	44	66.7	3,000	-1
6154400	Peoples Cr nr Hays, Mont	12	220	3,570	3
6154500	Peoples Cr nr Dodson, Mont	21	670	3,500	2
6155100	Black Coulee nr Malta, Mont	12	7.03	2,550	1
6155200	Alkali Cr nr Malta, Mont	17	162	2,470	0
6155300	Disjardin Coulee nr Malta, Mont	23	4.84	2,470	0
6155400	Taylor Coulee nr Malta, Mont	18	3.89	2,530	0
6156000	Whitewater Cr nr international boundary	51	458	2,820	-2
6158000	Frenchman R ab Eastend Res nr Ravenscrag, Sask	34	601	3,670	-4
6168500	Rock Cr at international boundary	35	241	2,910	-5
6169000	Horse Cr at international boundary	46	73.5	2,810	-5
6169500	Rock Cr bl Horse Cr nr international boundary	32	328	2,870	-5
6170000	McEachern Cr at international boundary	53	182	2,830	-5
6178000	M Fk Poplar R at international boundary	47	362	2,950	-5
6178500	E Poplar R at internatonal boundary	43	534	2,800	-5
6179500	W Fk Poplar R at international boundary	20	139	3,000	-5
6180000	W Fk Poplar R nr Richland, Mont	15	428	2,900	4
6182500	Big Muddy Cr at Daleview, Mont	25	279	2,510	-4
6183000	Big Muddy Cr at Plentywood, Mont	19	850	2,460	-4
6183100	Box Elder Cr nr Plentywood, Mont	19	9.40	2,380	-4
6183300	Spring Cr nr Plentywood, Mont	24	7.05	2,440	-4
6183400	Spring Cr at Highway 16 nr Plentywood, Mont	19	16.9	2,330	-4
6329700	Painted Woods Cr trib nr Williston, N Dak	19	0.37	2,150	-2
6329800	Painted Woods Cr nr Williston, N Dak	19	17.0	2,300	-2
6329900	Painted Woods Cr trib No. 2 nr Williston, N Dak	19	8.30	2,300	-2
6330100	Sand Cr nr Williston, N Dak	19	38.0	2,150	-2
6331000	Little Muddy Cr bl Cow Cr nr Williston, N Dak	24	775	2,110	-2
6331900	White Earth R trib nr Tioga, N Dak	14	9.60	2,400	-4

Station number	Station name	Years of record	Drainage area (A) (square miles)	Mean basin elevation (E) (feet above sea level)
	East-Central Plains Region			
6115100	Missouri R trib nr Landusky, Mont	16	3.39	2,690
6115300	Duval Cr nr Landusky, Mont	16	3.31	3,100
6120600	Antelope Cr trib nr Harlowton, Mont	18	0.47	5,400
6120700	Antelope Cr trib nr mouth nr Harlowton, Mont	18	1.92	5,200
6120800	Antelope Cr trib No. 2 nr Harlowton, Mont	23	21.2	4,570
6120900	Antelope Cr at Harlowton, Mont	22	88.7	4,930
6125700	Big Coulee nr Lavina, Mont	15	232	4,230
6126300	Current Cr nr Roundup, Mont	15	220	4,250
6127100	S Willow Cr trib nr Roundup, Mont	15	1.38	3,590
6127200	Musselshell R trib nr Musselshell, Mont	15	10.8	3,300
6127570	Butts Coulee nr Melstone, Mont	16	6.71	3,000
6128900	Box Elder Cr trib nr Winnett, Mont	19	16.2	2,900
6129000	Box Elder Cr nr Winnett, Mont	21	684	3,470
6129700	Gorman Coulee nr Cat Creek, Mont	16	2.32	2,910
6129800	Gorman Coulee trib nr Cat Creek, Mont	24	0.81	2,900
6130600	Cat Cr nr Cat Creek, Mont	16	36.5	2,870
6130800	Second Cr trib nr Jordan, Mont	17	0.52	2,830
6130850	Second Cr trib No. 2 nr Jordan, Mont	21	2.08	2,830
6130900	Second Cr trib No. 3 nr Jordan, Mont	15	0.72	2,780
6130950	Little Dry Cr nr Van Norman, Mont	18	1,220	2,860
6131000	Big Dry Cr nr Van Norman, Mont	38	2,550	2,870
6172300	Unger Cr nr Vandalia, Mont	21	11.1	2,560
6172350	Mooney Coulee nr Tampico, Mont	15	14.3	2,410
6174000	Willow Cr nr Glasgow, Mont	25	538	2,400
6175550	E Fk Sand Cr nr Vida, Mont	15	8.51	2,440
6175700	E Fk Wolf Cr nr Lustre, Mont	23	9.61	2,850
6175900	Wolf Cr trib No. 2 nr Wolf Point, Mont	24	6.54	2,470
6176500	Wolf Cr nr Wolf Point, Mont	25	251	2,570
6177050	E Fk Duck Cr nr Brockway, Mont	24	12.4	2,910
6177100	Duck Cr nr Brockway, Mont	15	54.0	2,910
6177150	Redwater R at Brockway, Mont	17	216	2,810
6177200	Tusler Cr nr Brockway, Mont	16	90.2	2,980
6177250	Tusler Cr trib nr Brockway, Mont	17	3.17	2,700
6177300	Redwater R trib nr Brockway, Mont	17	0.29	2,620
6177350	S Fk Dry Ash Cr nr Circle, Mont	17	5.74	2,840
6177400	McCune Cr nr Circle, Mont	18	29.9	2,810
6177500	Redwater R at Circle, Mont	41	547	2,810
6177700	Cow Cr trib nr Vida, Mont	16	1.71	2,490
6177800	Wolf Cr trib nr Vida, Mont	17	0.91	2,450
6181000	Poplar R nr Poplar, Mont	30	3,170	2,730
6181200	Missouri R trib No. 2 nr Brockton, Mont	15	1.60	2,170
6185100	Big Muddy Cr trib nr Culbertson, Mont	15	7.38	2,110
6185200	Missouri R trib No. 3 nr Culbertson, Mont	15	1.23	2,090
6185300	Missouri R trib No. 4 nr Culbertson, Mont	15	11.6	2,170
6185400	Missouri R trib No. 5 nr Culbertson, Mont	16	3.67	2,210
6217700	Crooked Cr trib nr Shepherd, Mont	17	7.21	3,650
6294900	M Fk Froze to Death Cr trib nr Ingomar, Mont	15	1.36	3,220
6295020	Short Cr nr Forsyth, Mont	17	3.23	2,820
6295050	Little Porcupine Cr nr Forsyth, Mont	18	614	2,910
6309020	Rock Springs Cr trib at Rock Springs, Mont	16	0.96	3,000
6309040	Dry House Cr nr Angela, Mont	15	35.6	2,940
6309060	N Fk Sunday Cr trib No. 2 nr Angela, Mont	17	0.22	2,710
6326900	Yellowstone R trib No. 4 nr Fallon, Mont	15	0.67	2,410
6326950	Yellowstone R trib No. 5 nr Marsh, Mont	16	0.82	2,440

Station number	Station name	Years of record	Drainage area (*A*) (square miles)	Forest cover (*F*) (percent)
	Southeast Plains Region			
6294400	Andresen Coulee nr Custer, Mont	16	2.35	31.0
6294800	Unknown Cr nr Bighorn, Mont	15	14.6	10.0
6294850	Buckingham Coulee nr Myers, Mont	15	2.63	29.0
6295100	Rosebud Cr nr Kirby, Mont	15	34.2	12.0
6295200	Whitedirt Cr nr Lame Deer, Mont	15	1.58	63.0
6296000	Rosebud Cr nr Forsyth, Mont	19	1,280	41.0
6296100	Snell Cr nr Hathaway, Mont	15	10.5	11.0
6306300	Tongue R at State line nr Decker, Mont	29	1,480	37.0
6306900	Spring Cr nr Decker, Mont	21	34.7	5.0
6306950	Leaf Rock Cr nr Kirby, Mont	19	4.53	10.0
6307640	Spring Cr nr Ashland, Mont	15	1.56	14.0
6307660	Walking Horse Cr nr Ashland, Mont	16	3.33	15.0
6307760	Stebbins Cr nr Ashland, Mont	15	5.41	64.0
6307780	Stebbins Cr at Mouth nr Ashland, Mont	16	20.8	37.0
6308200	Basin Cr trib nr Volborg, Mont	24	0.14	0.0
6308300	Basin Cr nr Volborg, Mont	19	10.9	1.7
6309080	Deep Cr nr Kinsey, Mont	17	11.5	0.0
6309090	Ash Cr nr Locate, Mont	15	6.23	17.0
6317050	Rucker Draw nr Spotted Horse, Wyo	18	3.98	0.0
6324700	Sand Cr nr Broadus, Mont	24	10.6	4.9
6325500	Little Powder R nr Broadus, Mont	25	1,970	7.4
6326400	Meyers Cr nr Locate, Mont	15	9.42	17.0
6326600	O'Fallon Cr nr Ismay, Mont	17	669	2.3
6326650	O'Fallon Cr trib nr Ismay, Mont	15	0.17	0.0
6326700	Deep Cr nr Baker, Mont	15	1.55	0.0
6326800	Pennel Cr nr Baker, Mont	17	1.00	0.0
6328800	Indian Cr at Intake, Mont	16	0.46	0.0
6328900	War Dance Cr nr Intake, Mont	16	3.69	0.0
6329570	First Hay Cr nr Sidney, Mont	16	30.0	0.0
6334000	Little Missouri R nr Alzada, Mont	53	904	8.0
6334100	Wolf Cr nr Hammond, Mont	24	9.09	0.0
6334200	Willow Cr nr Alzada, Mont	16	123	0.0
6334500	Little Missouri R at Camp Crook, S Dak	24	1,970	5.6
6334630	Box Elder Cr nr Webster, Mont	15	1,090	4.2
6334640	N Fk Coal Bank Cr nr Webster, Mont	15	15.0	0.0
6334720	Soda Cr trib nr Webster, Mont	17	2.22	0.0
6335000	Little Beaver Cr nr Marmarth, N Dak	39	587	0.0
6335700	Deep Cr nr Bowman, N Dak	19	0.20	0.0
6336100	Sheep Cr trib nr Medora, N Dak	15	0.29	0.0
6336200	Sheep Cr trib No. 2 nr Medora, N Dak	16	0.42	0.0
6336300	Little Missouri R trib nr Medora, N Dak	19	0.32	0.0
6336400	Jules Cr nr Medora, N Dak	19	3.80	0.0
6336450	Spring Cr nr Wibaux, Mont	17	3.88	0.0
6336500	Beaver Cr at Wibaux, Mont	35	351	0.0
6336980	Little Missouri R trib nr Watford City, N Dak	14	2.10	0.0
6337100	Spring Cr nr Watford City, N Dak	14	22.7	0.0
6356000	S Fk Grand River at Buffalo, S Dak	24	148	0.5
6358600	S Fk Moreau R trib nr Redig, S Dak	22	2.33	0.0
6358620	Sand Cr trib nr Redig, S Dak	16	0.04	0.0

☆ GPO 799-074

SECTION 3.6
SYNTHETIC HYDROGRAPH

APPENDIX A

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Prepared in cooperation with the
MONTANA DEPARTMENT OF HIGHWAYS,
FEDERAL HIGHWAY ADMINISTRATION,
U.S. FOREST SERVICE,
and the
U.S. BUREAU OF LAND MANAGEMENT

OPEN-FILE REPORT 81-917
PLATE 1

EXPLANATION

—— 30 —— LINE OF EQUAL MEAN ANNUAL PRECIPITATION, INTERVALS 2, 10, AND 20 INCHES

SCALE 1:1 000 000

0 10 20 30 40 MILES
0 10 20 30 40 KILOMETERS

Base from U.S. Geological Survey
State base map, 1:500,000, 1968

MAP SHOWING MEAN ANNUAL PRECIPITATION, 1953-67, WEST AND NORTHWEST REGIONS, MONTANA

SECTION 3.6
SYNTHETIC HYDROGRAPH

3.6 SYNTHETIC HYDROGRAPH DEVELOPMENT

Introduction

When sizing a culvert by the method outlined in Section 4.9, Flood Routing Method of Culvert Design, it is necessary to have a hydrograph of the design storm instead of just the peak flow. As there is rarely a recording gage in place at these locations, it is necessary to synthesize a hydrograph that can be used for design purposes.

There are two synthetic hydrograph development methods available which give reasonable results. One is the method presented in the Soil Conservation Service National Engineering Handbook, Section 4, Hydrology, for developing the emergency spillway hydrograph. The other method is presented by Barnes, Edminster, Frevert, and Schwab in Soil and Water Conservation Engineering, 2nd Edition. Both methods use the SCS method of determining direct runoff based on watershed paramenters and amount of rainfall.

The direct runoff is given by the following formula:

$$q = \frac{(I-.2S)^2}{I+.8S}$$

where

q = direct surface runoff in inches

I = storm rainfall in inches

S = soil index

The soil index is determined as outlined in Appendix A. The storm rainfall can be determined from Figure 3.12 or 3.13. The SCS recommends that 6 hours be used as the minimum storm period.

A short discussion of each method will be given here but the cited references should be consulted for a detailed discussion of the methods.

3.61 METHODS OF SYNTHETIC HYDROGRAPH DEVELOPMENT

SCS Method - The emergency spillway hydrograph (ESH) development procedure is outlined in Chapter 21 of Section 4 of the SCS National Engineering Handbook. This method uses the direct runoff, the time of concentration, and a series of dimensionless hydrographs to produce the runoff hydrograph. The time of concentration can be determined as outlined in Section 3.5. This method is more complicated than the Soil and Water Conservation Engineering method but it may give slightly more reasonable results.

Soil and Water Conservation Engineering Method - This method is presented in Chapter 4 of Soil and Water Conservation Engineering. This method uses the direct runoff, the peak runoff and a dimensionless hydrograph to produce the runoff hydrograph. The use of this method is quite simple and can be solved by the use of computer program "HYD Basic".

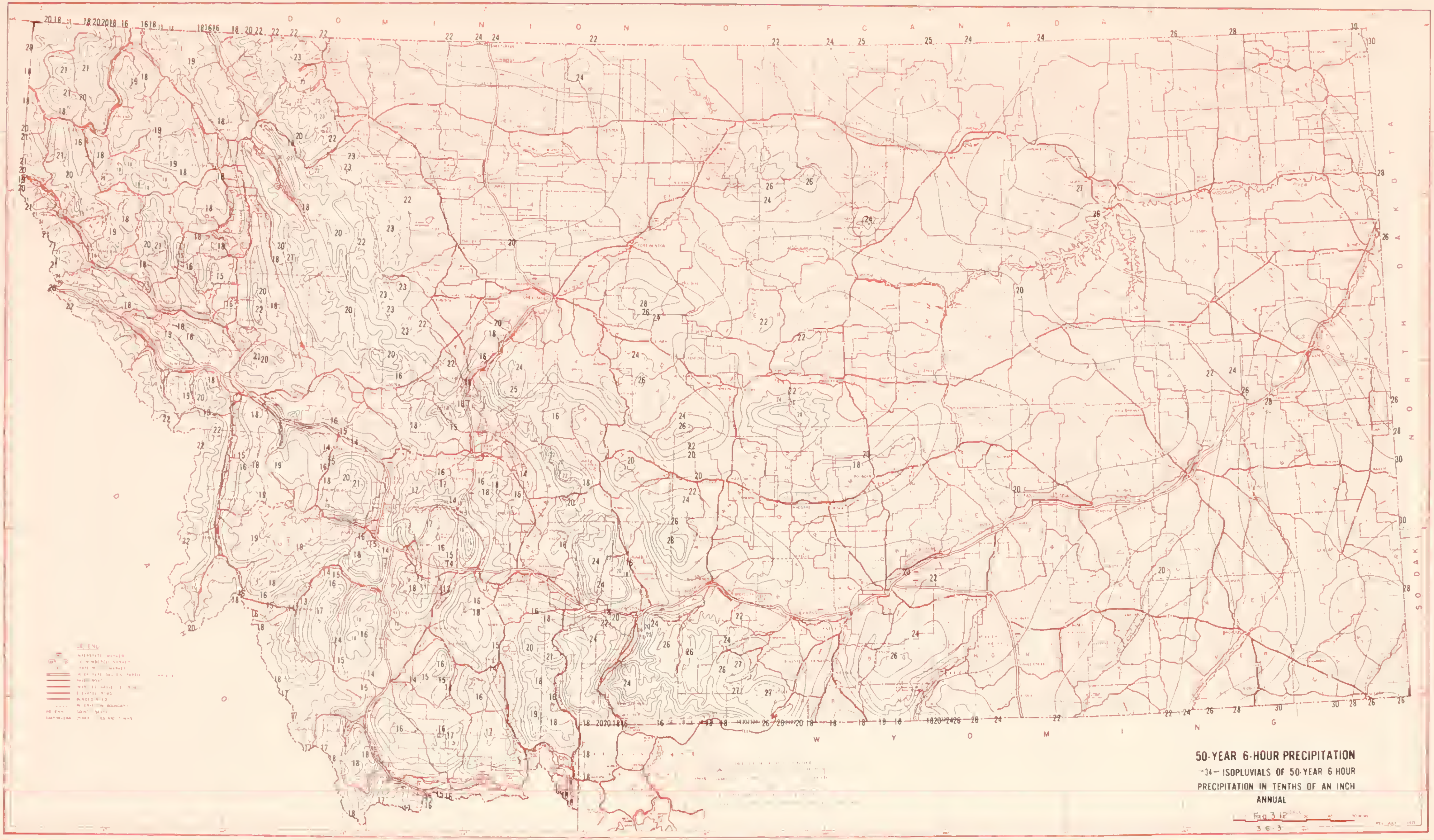
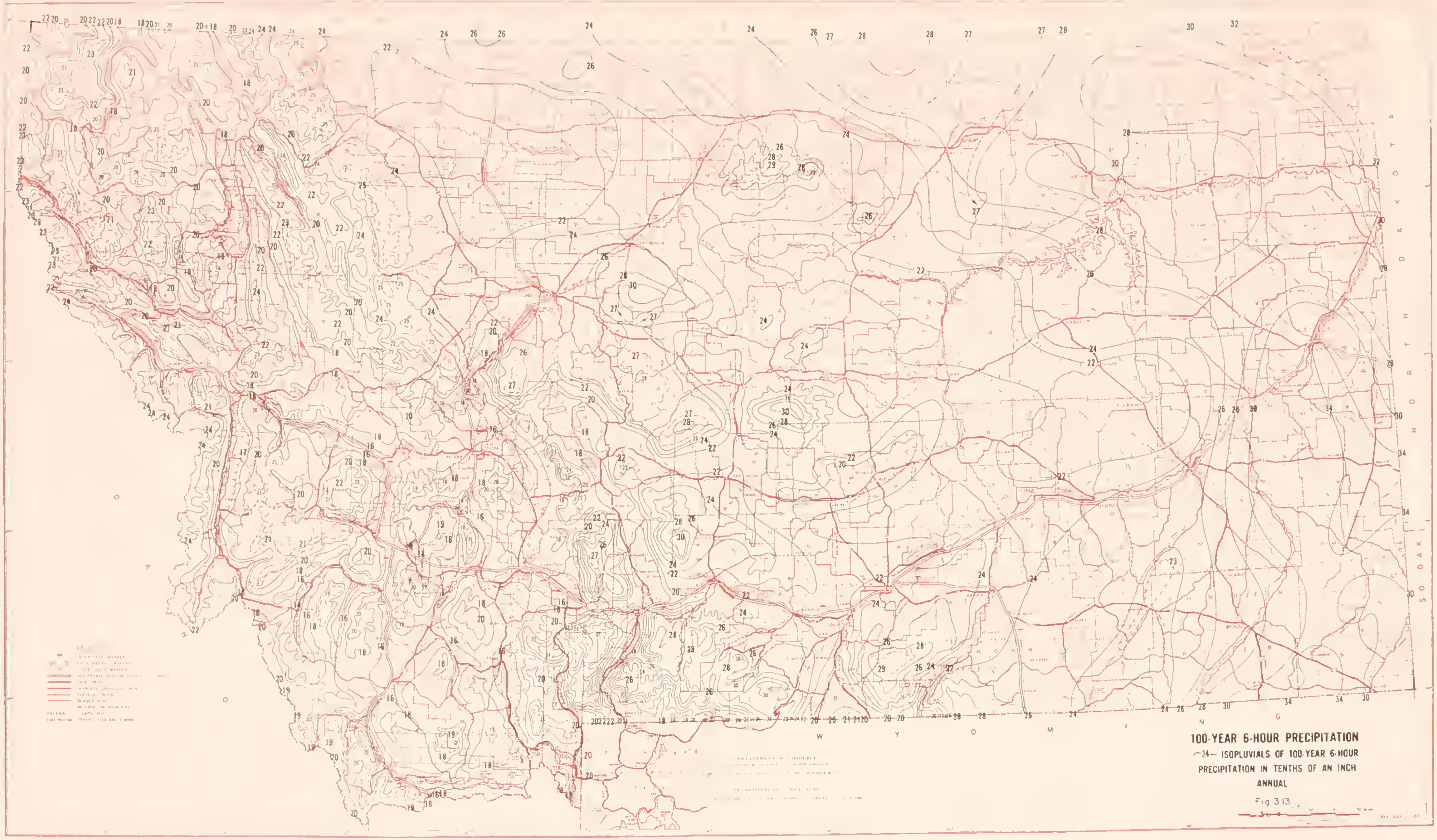

DOMINION OF CANADA
NORTH DAKOTA
SO DAK
WYOMING
IDAHO
50-YEAR 6-HOUR PRECIPITATION
—34— ISOPLUVIALS OF 50-YEAR 6 HOUR PRECIPITATION IN TENTHS OF AN INCH
ANNUAL

Fig 3.12
3-6-3



100-YEAR 6-HOUR PRECIPITATION
—34— ISOPLUVIALS OF 100-YEAR 6-HOUR PRECIPITATION IN TENTHS OF AN INCH
ANNUAL
Fig 3.13
WYOMING
NORTH DAKOTA
SOUTH DAKOTA

3.62 COMPUTER PROGRAM AND EXAMPLE

The following discussion of computer program "HYD Basic" and the following example show the development of a synthetic runoff hydrograph.

Name: HYD   Language: Basic   Input Format: Run

Purpose: This program produces a synthetic runoff hydrograph.

Required Input: The flood peak in cfs, the total direct runoff in inches, and the drainage area in square miles are required.

Abstract: This program is based on the synthetic hydrograph development procedure outlined in Chapter 4 of <u>Soil and Water Conservation Engineering</u>. The program uses the direct runoff, the peak flow, and a built-in dimensionless hydrograph to develop a runoff hydrograph.

Example: Develop and plot the 50-year runoff hydrograph for a watershed of 1.35 square miles near Sidney. This watershed consists entirely of rangeland with a hydrologic soil group B.

Using the Dodge Method of Section 3.41 for Region V

$$Q_{50} = 180 \text{ cfs}$$

From Appendix A the curve number, CN, is 79. Therefore, the soil index, S, is

$$S = \frac{1000}{CN} - 10 = \frac{1000}{79} - 10$$
$$= 2.65$$

From figure 3.12, the 50-year 6-hour precipitation, I, for this location is 3.0 inches. Therefore, the direct runoff, q, is

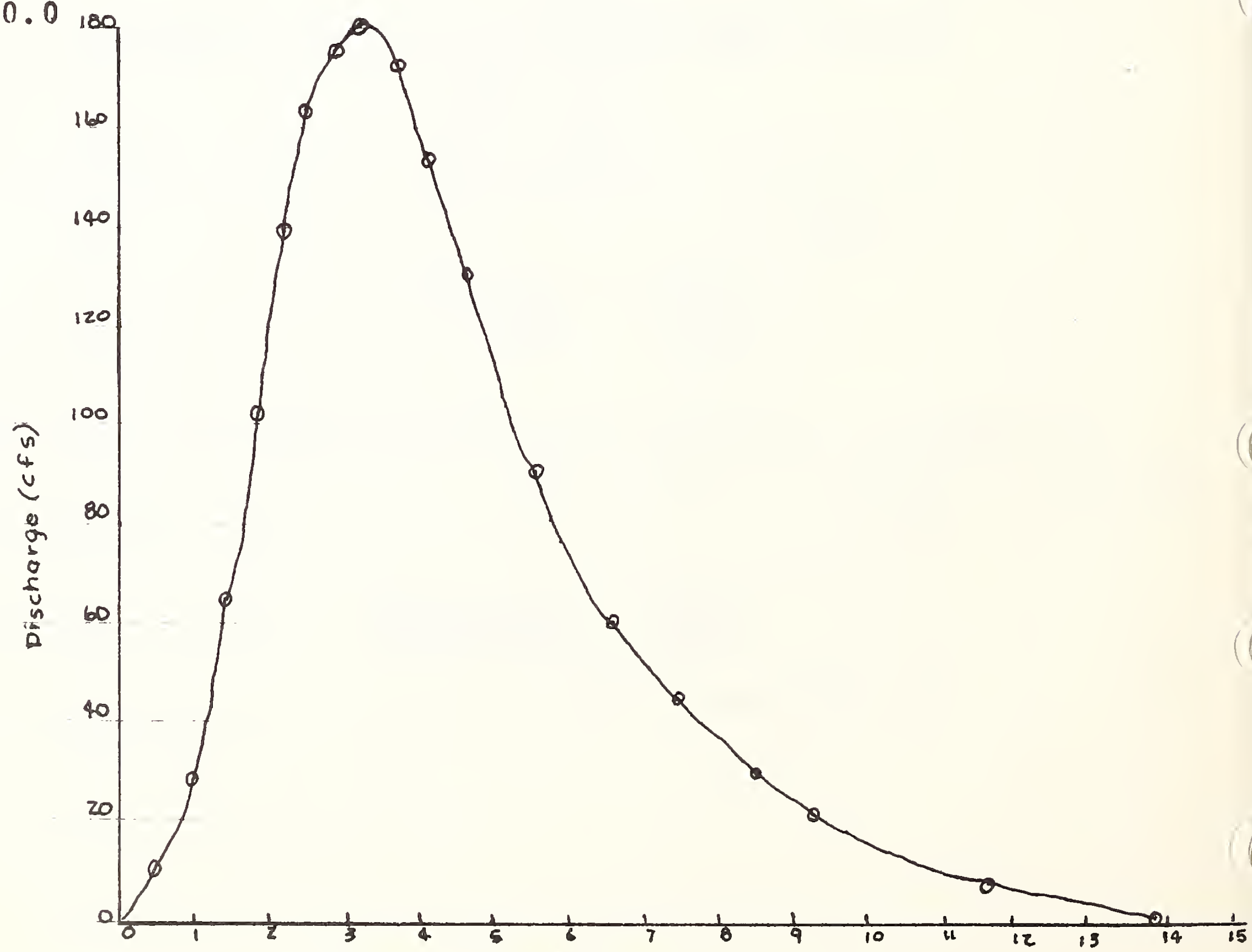
$$q = \frac{(I-.2S)^2}{I+.8S} = \frac{(2.6-.2x2.65)^2}{2.6+.8x2.65}$$

q = .95 inches of runoff

```
     edit hyd basic
EDIT  run
SYNTHETIC HYDROGRAPH DEVELOPMENT


INPUT FLOOD PEAK(CFS), RUNOFF(INCHES), AMD DRAINAGE AREA(SQ. MI.)
  ?   180,.95,1.35


TIME(HRS) FLOW(CFS)
  0.0      0.0
  0.4      9.0
  1.0     27.0
  1.4     63.0
  1.8    100.8
  2.2    138.6
  2.5    162.0
  2.8    174.6
  3.2    180.0
  3.8    172.8
  4.2    153.0
  4.7    129.6
  5.6     90.0
  6.5     59.4
  7.4     43.2
  8.4     28.8
  9.3     19.8
 11.7      7.2
 13.9      0.0
EDIT
```



3.6-6

References

1. Design of Small Dams, U.S. Department of the Interior, Bureau of Reclamation, U.S. Government Printing Office, Washinton, D.C., 1960.

2. Schwab, G. O., R. K. Frevert, T. W. Edminster, and K. K. Barnes, Soil and Water Conservation Engineering, John Wiley and Sons, Inc., New York, 1966.

3. SCS National Engineering Handbook, Section 4, Hydrology, U.S. Department of Agriculture, Soil Conservation Service, U.S. Government Printing Office, Washington, D. C., 1971.

APPENDIX A

Appendix A

The Soil Index

The soil index, S, for a drainage area is a concept developed by the U.S. Soil Conservation Service. The soil index is a parameter which attempts to describe the interception, infiltration and surface storage characteristics of the soil. Chapters 7 through 10 of SCS National Engineering Handbook, Section 4, Hydrology, give a detailed description and procedure for determining the soil index.

The soil index value, S, is a function of the weighted curve number, CN, as given by the relation

$$S = \frac{1000}{CN} - 10$$

This equation gives values of S ranging from 0 for CN = 100 to 10 for CN = 50 and approaching infinity for extremely small values of CN. Most natural watersheds in Montana will have a S value ranging from a low of about 2.0 to a high of about 9.0.

The CN value for a watershed is dependent upon its hydrologic soil group, its hydrologic condition, and its land use or cover. Values of Curve Number for various conditions are given in Table A.

TABLE A

Values of Curve Number for Various
Cover-Soil Groupings for Moisture Condition II

Land Use or Cover	Treatment	Hydrologic Condition	Hydrologic Soil Group: A	B	C	D
Fallow	St. Row	--	77	86	91	94
Row Crops	"	Poor	72	81	88	91
	"	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	"	Good	65	75	82	86
	C & T*	Poor	66	74	80	82
	C & T*	Good	62	71	78	81
Small Grain	St. Row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	C & T	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded legumes1/	St. Row	Poor	66	77	85	89
	"	Good	58	72	81	85
or	Contoured	Poor	64	75	83	85
rotation	"	Good	55	69	78	83
meadow	C & T*	Poor	63	73	80	83
	"	Good	51	67	76	80
Pasture		Poor	68	79	86	89
or range		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	"	Fair	25	59	75	79
	"	Good	6	35	70	79
Meadow (Permanent)		Good	30	58	71	78
Woods (Farm Woodlots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		--	59	74	82	86
Roads (dirt)2/		--	72	82	87	89
(hard surface)2/		--	74	84	90	92

1/ Close-Drilled or broadcast
2/ Including right-of-way
* Contoured and Terraced

The hydrologic soil groups, as defined by SCS soil scientists, are:

A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, excessively drained sands or gravels. These soils have a high rate of water transmission.

B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

The hydrologic soil group of a watershed can be determined by either of two methods. The SCS has published soil maps for many parts of the State. If the watershed under study is located in one of the areas mapped then the soil groups can be determined directly from the soil map. If soil maps are not available for the watershed under consideration, then the nearest local office of the SCS should be contacted and they can provide the required hydrologic soil group information.

The hydrologic condition is usually defined as Good, Fair, or Poor and relates to vegatative condition, land treatment, and land use. Chapters 8 and 9 of the SCS National Engineering Handbook give a detailed discussion of these

relationships. The hydrologic condition of native pasture or range is given below as an example.

Poor - Heavily grazed. Has no mulch or has plant cover no less than 1/2 of the area.

Fair - Not heavily grazed. Has plant cover on 1/2 to 3/4 of the area.

Good - Lightly grazed. Has plant cover on more than 3/4 of the area.

Descriptions of the land users and cover given in Table A can be found in Chapter 8 of the SCS National Engineering Handbook.

When different curve numbers apply to different parts of a watershed it is necessary to determine a weighted curve number for the watershed. The following example illustrates the procedure.

Determine the soil index for a watershed with the following data:

Use or Cover	Condition	Soil	% Area	CN	weighted CN
Fallow		A	15	77	11.5
Small Grain St. Row	Good	A	15	63	9.4
Pasture	Good	A	10	39	3.9
Range	Fair	B	20	69	13.8
Meadow	Good	C	10	71	7.1
Forest	Poor	D	30	83	24.8
			100		70.6 say 71

The weighted CN value for the watershed calculated in the last 2 columes is estimated as 71 as shown above. The S value for this watershed is

$$SI = \frac{1000}{71} - 10 = 14.1 - 10 = 4.1$$

References

1. SCS National Engineering Handbook, Section 4, Hydrology, U.S. Department of Agriculture, Soil Conservation Service, U.S. Government Printing Office, Washington, D.C., 1971.

GLOSSARY

The definitions in this Glossary are for general use in this Manual. Other definitions are defined in the text as they are required.

Aerobic Bacteria - Those bacteria that require the presence of oxygen to live and multiply.

Alternating Siphons - A pair of siphons used in conjunction with a dosing tank that will alternate the sewage loading between two drain fields thus giving the drain.

Anaerobic Bacteria - Those bacteria which can live and multiply without the presence of free oxygen.

Apron - A floor of lining at the outlet end of a culvert chute or other waterway structure to protect the waterway from erosion from falling water or turbulent flow.

Backwater - The water retarded above a dam, bridge, or other constriction, or backed up into a tributary by a flood in the main stream.

Backwater Curve - The term applied to the profile of the water surface in a channel or reservoir during steady but non-uniform flow.

Base Flow - That portion of stream flow that comes from groundwater.

Bedload - The sediment that moves by sliding, rolling, or bounding on or very near the stream bed or sediment moved mainly by tractive or gravitational forces or both but at velocities less than the surrounding flow.

BOD - Biochemical Oxygen Demand; BOD is the measure of the unstable organic material in sewage. The BOD is the amount of oxygen required for the aerobic decomposition of the unstable organic material.

Calculated Highwater - The water surface elevation that can be expected during the design flood.

Cavitation - When a liquid in a pipe system flows into a region where its pressure is reduced to its vapor pressure, vapor pockets develop in the liquid. These vapor bubbles are carried along with the liquid until a region of higher pressure is reached where they suddenly collapse causing very high localized pressures. This formation and collapse of vapor pockets is called cavitation. Cavitation reduces efficiency and causes pump damage.

Channel Bottom Elevation - The elevation of the lowest point of the channel at a given cross section.

Channel Width, B - That channel bottom width that could be expected if the slopes of the bridge approaches were projected to the points where they intersect the channel bottom elevation. The distance between these points of intersection, measured normal to the stream, is the channel bottom width.

Combined Sewer - A closed conduit carrying both sanitary sewage and storm water.

Constriction - Something that causes a reduction in the waterway opening area of a stream.

Conveyance, K - A measure of the carrying capacity of a channel; it is directly proportional to flow. By the Manning formula:

$$K = \frac{1.49}{n} AR^{2/3}$$

Cutoff - A wall, collar, or other structure of relatively impervious material intended to reduce seepage of water under or around a structure.

Debris - Undesirable material either floating, heavier than water or a combination of both, that is carried by a stream which can be deposited at culvert entrances and other constrictions causing channel plugging.

Ditch Lining - A protective covering over all or part of the perimeter of a channel to prevent seepage losses, resist erosion, reduce friction or other wise improve conditions of flow.

Dosing Tank - A tank used in conjunction with a septic tank and drainfield to obtain proper distribution of sewage throughout the drainfield and give the absorption bed a chance to rest or dry out between dosings. Automatic alternating siphons discharge the tank periodically.

Drainage Area - The area contributing to a single drainage basin, expressed in acres or square miles. Also called watershed or river basin.

Drawdown - The drop in water surface elevation in a well from the static level to the pumping level.

Energy Gradient - The total energy level of water at all points along a longitudinal line. It is the sum of velocity head, pressure head and elevation of a flowing body of water.

Flashboard - A temporary barrier of relatively low height and usually constructed of wood, used in checks to control water surface elevations and flow.

Flood -

a. Annual Flood - The highest peak discharge in a 12 month period.

b. Basic Flood - The flood magnitude which is equaled or exceeded on the average of once in 100 years. It is also called the Intermediate Project Flood.

c. Mean Annual Flood - A flood equal to the mean of the discharges of all of the maximum annual floods during the period of record, and which has a recurrence interval of 2.33 years for the Gumbel Distribution.

d. Design Flood - The amount of runoff for which the features of river or stream are sized.

Flood - (Cont'd)

e. Intermediate Regional Flood - The flood that has an average frequency of occurrence in the order or once in 100 years.

f. Standard Project Flood - A flood which may be expected from the most severe combination of meteorologic and hydrologic conditions that are considered reasonable characteristics of the geographic area under consideration, excluding extremely rare combinations. Also called the maximum probable flood.

Flood Plain - The relatively flat or lowland area adjoining a river, stream or watercourse, which has been or may be temporarily covered by flood waters.

Flood Probability - The probability of a flood of given size being equaled or exceeded in a given period. A probability of one percent would be the flood expected to be equaled or exceeded once in 100 years; a probability of 10 percent would be a 10 year flood.

Flowline - The position of the water surface in a flowing stream or conduit for a normal or specified rate of discharge. The hydraulic grade line in an open channel.

Freeboard - The vertical distance between the maximum level of the surface of the water in a conduit, reservoir, tank, basin, canal, etc. and the top of the confining structure, which is provided so that waves and other movements of the water will not overtop the confining structure.

Froude Number - A flow parameter, which is a measure of the extent to which gravitational action affects the flow. A froude number greater than 1 indicates supercritical flow and a value less than 1

Froude Number -

subcritical flow. The simplest form of the froude number is given by the equation:

$$F = \frac{V}{\sqrt{gD}}$$

where V is velocity, g the acceleration due to gravity (32.2 ft/sec^2), and D, the depth of flow.

Gabion - A wire basket filled with rock or stone and installed with other gabions to provide protection against erosion.

Gages - Instruments for measuring river stages and thus flow

a. Crest stage gage - A stage - measuring device which records only the peak stage.

b. Water - Stage Recorder - A gage which records the water stage continuously.

c. Stage - Rainfall Gage - A instrument for measuring rainfall and the runoff event caused by the rainfall.

Headwater - 1. The upper reaches of a stream near its source. 2. The water upstream from a structure.

Hydraulic Gradient - A hydraulic profile of the piezometric level of the water, representing the sume of the depth of flow and the pressure head. In open channel flow it is the water surface.

Hydraulic Radius, R - The ratio of water area to wetted perimeter.

Hydrograph - A graph showing flow versus time at a given point on a stream of conduit.

Impervious - A term applied to a material through which water cannot pass, or through which water passes with great difficulty.

Infiltration - 1. The entering of water through the interstices or pores of a soil or other porous medium. 2. The quantity of groundwater which leaks into a sewer through defective joints. 3. The absorption of liquid water by the soil, either as it falls as precipitation, or from a stream flowing over the surface.

Invert - The floor, bottom, or lowest portion of a conduit or structure.

Left Bank - The left-hand bank of a stream or dam when the observer is facing downstream.

Non-Uniform Flow - Flow that varies in depth and velocity along the channel.

Normal Stage - The water surface elevation in a stream during the design flood before any changes or constrictions are made.

Oriffice - An opening with closed perimeter, and of regular form in a plate, wall, or partition through which water may flow.

Overbank - That portion of the flood plain which is above the average flow level.

Parametric Hydrology - The development of relationships amoung physical parameters affecting runoff and the use of these relationships to generate or synthesize, hydrologic events.

Percolation - The downward movement of water through soil.

Permeability - The property of a material which permits movement of water through it when saturated and actuated by gravitation.

pH - A numerical measure of the acidity or alkalinity. The neutral point is pH 7.0. All pH values below 7.0 are acid and all above 7.0 are alkaline.

Piezometric Level - The free water surface in an open tub or the sum of the elevation head and pressure head in a confined system.

Pumping Level - The level of the water surface in a well when water is being pumped out from the well at a given rate.

Rainfall Intensity - The rate at which rain is falling at any given instant, expressed in inches per hour.

Reach - Any length of river or chanel. Usually used to refer to sections which are uniform with respect to discharge, depth, area, or slope, or sections between gaging stations.

Recurrence Interval - The average interval of time within which a given event will be equalled or exceeded once. For an annual series the probability of occurrence in any one year is the inverse of the recurrence interval. Thus a flood having a recurrence

Recurrence Interval - (Cont'd)

interval of 100 years has a 1 percent probability of being equalled or exceeded in any one year.

Reynold's Number - A flow parameter which is a measure of the viscous effects on the flow. It is given by the formula

$$R_e = \frac{VD}{\nu}$$

where V is velocity, D is depth and ν is the kinematic viscosity of the fluid.

Right Bank - The right-hand bank of a stream or dam when the observer is facing downstream.

Runoff Coefficient - A decimal number used in the Rational Formula which defines the runoff characteristics of the drainage area under consideration. It may be applied to an entire drainage basin as a composite representation or it may be applied to a small individual area.

Sanitary Sewer - A closed conduit carrying sewage and other waste liquids, but not including intentionally added surface and storm water.

Scour - The erosive action of running water in streams or channels, by excavating and carrying away material from the bed and banks.

Scum - The partically submerged mat of floating solids that may form at the surface of the fluid in septic tanks.

Sediment - Material of soil and rock origin transported, carried, or deposited by water.

Septic Tank - A tank which provides for the partial removal of solids from sewage by bacterial disintegration. The tank stores scum and sludge.

Settling Basin - An enlargement in a channel or conduit which greatly reduces velocities and permits the settling of debris and sediment carried in suspension.

Sludge - The accumulation of the heavier sewage solids at the bottom of a tank.

Spur Dike - A dike placed at the end of bridge approaches which encroach on wide flood plains to reduce scour at the bridge piers, approaches, or abutments.

Static Water Level - The level to which water raises in a well when no pumping is taking place.

Stilling Basin - An open structure or excavation at the base of an outfall, chute, drop, or spillway to reduce the energy of the descending stream.

Stochastic Hydrology - The statistical analysis of recorded events to predict flood events.

Stream -

a. Continuous - A stream which habitually flows or contains water throughout its entire course, or between any two points on its course.

b. Effluent - A stream or stretch of stream which receives water from ground water in the zone of saturation.

c. Ephemeral - A stream which flows only in direct response to precipitation. Such a stream receives no water from springs, and no long-continued supply from melting snow or other surface source.

d. Influent - A stream or stretch of stream which contributes water to the water table. The water surface of such a stream stands at a higher level than the water table.

e. Intermittent - A stream which flows during protracted periods, but not continually, when it receives water from springs or surface runoff.

f. Perennial - A stream which flows continuously at all seasons of the year and during dry as well as wet years.

Sump - A pit or reservoir located at low point of a drainage system.

Thalweg - The line defining the lowest part of a valley or channel.

Time of Concentration - The time required for storm runoff to flow from the most remote point of a catchment or drainage area to the outlet or point under consideration.

Time of Inlet - The time required for storm water to flow from the most distant point of a drainage area to the point where it enters a storm drain inlet.

Turbidity - The capacity of materials suspended in water to scatter light. Highly Turbid water is often called muddy, although all manner of suspended particles contribute to turbidity.

Uniform Flow - Uniform flow occurs only in a uniform channel when resistance and gravity forces are in exact balance. For uniform flow the energy gradient, water surface, and channel bottom are all parallel.

Water Hammer - The hydraulic shock which occurs when a non-viscous liquid like water, flowing through a pipe, undergoes a sudden change in velocity. The kinetic energy of the flowing liquid, due to its velocity, is converted into a dynamic pressure wave, which may produce terrific impact in rebounding back and forth in the main. Water hammer can reach destructive magnitudes, especially in long pipes.

Water Year - October 1 to September 30.

Weir - A water measurement structure which constricts the channel and causes the water to pond behind it and flow over it or through it. By measuring the height of the upstream water surface, the rate of flow is determined.

Well Capacity - The maximum sustained yield of a well during periods of low ground water table.

Wetted Perimeter WP - That portion of conduit wall or stream bed which is in contact with the fluid (free water surface excluded).

Vortex - The whirling or circular motion of water which tends to form a cavity or vacuum in the center of the circle and draw toward this cavity bodies subject to its action.